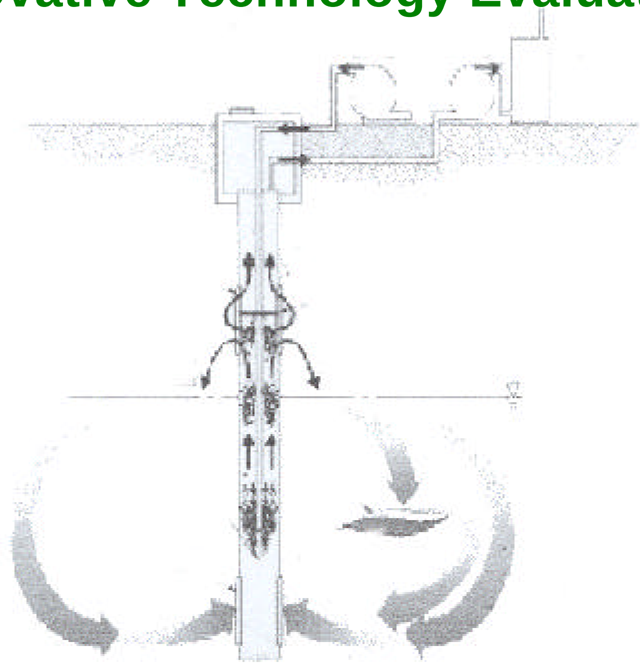
Technology Evaluation Report
for the
NoVOCs™ Technology Evaluation
Superfund Innovative Technology Evaluation Program



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Prepared by:

Tetra Tech EM Inc.
San Diego, California

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Volume I: Technology Evaluation Report
Appendix A: Auxillary Tables and Graphs, Appendix B: Vendor Case Studies
Appendix C: Hydrogeological Report

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MACTEC, Inc.

NoVOCs™ Technology

Technology Evaluation Report

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

Notice

The information in this document has been funded by the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Program under Contract No. 68-C5-0036, Work Assignment No. 0-37 to Tetra Tech EM Inc. It has been subjected to EPA's peer and administrative reviews and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

Foreword

The U.S. EPA is charged by Congress with protection the National's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

The Superfund Innovative Technology Evaluation (SITE) Program was authorized by the Superfund Amendments and Reauthorization Act of 1986. The Program, administered by EPA, is intended to accelerate the development and use of innovative cleanup technologies applicable to Superfund and other hazardous waste sites. This purpose is accomplished through technology evaluations designed to provide performance and cost data on selected technologies.

An evaluation of the MACTEC Inc., NoVOCs™ technology was conducted under the SITE Program, in partnership with the Naval Facilities Engineering Command Southwest Division, the Navy Environmental Leadership Program, the EPA Technology Innovation Office, and Clean Sites, Inc. Specifically, the NoVOCs™ technology performance in treating groundwater contaminated with volatile organic compounds (VOC) at Naval Air Station North Island, Installation Restoration Site 9 was evaluated. The results of the evaluation, including information on the performance and cost of the technology, are presented in this Technology Evaluation Report (TER). Because of operational difficulties encountered during the demonstration, a complete evaluation of the performance and cost characteristics of the NoVOCs™ technology's ability to treat VOC-contaminated groundwater could not be conducted. However, valuable information was collected regarding the operation and maintenance of the NoVOCs™ technology and site-specific factors that may influence the performance and cost of the system. This information may be useful to decision-makers when carrying out specific remedial actions using this technology or conducting further technology performance evaluations. Data from the SITE evaluation may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from the field evaluation documented in this TER.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

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Joe Aiken	MACTEC, Inc.
Rafat Abbasi	DTSC Project Manager
Steve Baker	Umtanum Enterprises
Charles Cheng	RWQCB Project Manager
John Clark	Thermatrix, Inc.
Bill Collins	SWDIV Installation Restoration Program Manager
Dave Demars	SWDIV Remedial Project Manager
Scott Donavan	Bechtel National, Inc.
Annette Gatchett	EPA/NRMRL/SITE Program Manager
Eric Jensen	MACTEC, Inc., Subcontractor
Ann Kern	EPA/NRMRL Divisional Quality Assurance Manager
Jim Kozakowski	Bechtel National, Inc.
Fayaz Lakhuala	MACTEC, Inc., Subcontractor
Mike Magee	NELP Program Manager
Mark McGlathery	MACTEC, Inc.
Charles Miller	Gilbert Hill Associates
Debbie Newberry	Clean Sites Project Manager
Rich Rolfe	San Diego APCD
Warren Schultz	MACTEC, Inc.
Michelle Simon	EPA/NRMRL Work Assignment Manager
Gary Turner	EPA/TIO Project Manager
Melinda Trizinsky	Clean Sites Technical Program Manager

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Acronyms and Abbreviations

APCD	Air Pollution Control District
APHA	American Public Health Association
ARAR	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
ATTIC	Alternative Treatment Technologies Information Center
Bechtel	Bechtel National, Inc.
bgs	Below ground surface
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CERI	Center for Environmental Research Information
cm/sec	Centimeters per second
CPT	Cone penetrometer test
DCA	Dichloroethane
DCE	Dichloroethene
DNAPL	Dense nonaqueous-phase liquid
EG&GE	EG&G Environmental
Eh	Reduction/oxidation potential
EPA	U. S. Environmental Protection Agency
EF	Degree Fahrenheit
ft/day	Feet per day
ft/ft	Feet per foot
ft 2 /day	Square feet per day
gpm	Gallons per minute
gpm/ft	Gallons per minute per foot
g/cm 3	Grams per cubic centimeter
HCl	Hydrochloric acid
HP	Horsepower
IR	Installation Restoration
kWh	Kilowatt hour
kW/HP	Kilowatt per horsepower
MACTEC	MACTEC, Inc.
MCAWW	Method for the Chemical Analysis of Water and Wastes
MCL	Maximum contaminant levels
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
MLLW	Mean lower low water
MS	Matrix spike
MSD	Matrix spike duplicate
mv	Millivolts
NA	Not analyzed
NC	Not calculated
NAS	Naval Air Station
NELP	Navy Environmental Leadership Program
NOAA	National Oceanic and Atmospheric Administration
NTU	Nephelometric turbidity units

Acronyms and Abbreviations Cont.

NRMRL	National Risk Management Research Laboratory
NTIS	National Technical Information Service
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
PAH	Polynuclear aromatic hydrocarbon
PCE	Tetrachloroethene
ppb v/v	Parts per billion on a volume per volume basis
PPE	Personal protective equipment
ppm	Parts per million
psi	Pounds per square inch
PVC	Polyvinyl chloride
QA/QC	Quality assurance/quality control
QAPP	Quality assurance project plan
RCRA	Resource Conservation and Recovery Act
RPD	Relative percent difference
RTU	Remote telemetry unit
RWQCB	Regional Water Quality Control Board
SARA	Superfund Amendments and Reauthorization Act
SRB	Sulfur reducing bacteria
scfm	Standard cubic feet per minute
SITE	Superfund Innovative Technology Evaluation
SVOC	Semivolatile organic compound
SWDIV	Naval Facilities Engineering Command Southwest Division
SW-846	U.S. EPA Test Methods for Evaluating Solid Wastes
1,1,1-TCA	1,1,1-Trichloroethane
TCE	Trichloroethene
TDS	Total dissolved solids
TEP	Test evaluation plan
TER	Technology evaluation report
Tetra Tech	Tetra Tech EM Inc.
Thermatrix	Thermatrix, Inc.
TIO	Technology Innovation Office
VOC	Volatile organic compound
UCL	Upper confidence limit
VISITT	Vendor Information System for Innovative Treatment Technologies
WC	Water column
µg/L	Micrograms per liter
µmhos/cm	Micromhos per centimeter

EXECUTIVE SUMMARY

This Technology Evaluation Report (TER) summarizes the findings of an evaluation of the MACTEC, Inc. (MACTEC), NoVOCs™ in-well volatile organic compound (VOC) stripping system by the U.S. Environmental Protection Agency (EPA), National Risk Management Research Laboratory, Superfund Innovative Technology Evaluation (SITE) Program. The report also includes performance data on the Thermatrix, Inc. (Thermatrix), flameless oxidation system, which was used to treat offgas from the NoVOCs™ system. The NoVOCs™ system was demonstrated at Installation Restoration Site 9 at the Naval Air Station (NAS) North Island in San Diego, California, and was evaluated over an 11-month period from February 1998 to January 1999. The evaluation focused on the ability of the NoVOCs™ system to treat groundwater contaminated with VOCs, specifically, tetrachloroethene, trichloroethene (TCE), dichloroethene (DCE), vinyl chloride, benzene, toluene, ethylbenzene, and xylene.

The demonstration was conducted in partnership with Naval Facilities Engineering Command Southwest Division (SWDIV), Navy Environmental Leadership Program, the EPA Technology Innovation Office, and Clean Sites, Inc. Both the NoVOCs™ and Thermatrix systems were operated and monitored by SWDIV's support contractor, Bechtel National, Inc. (Bechtel). This report summarizes data collected by all involved parties and includes a comprehensive description of the demonstration at NAS North Island and its results.

The NoVOCs™ system did not function without operational difficulties in the highly saline aquifer containing groundwater with total dissolved solids ranging from 18,000 to 41,000 mg/L, which represents an extreme geochemical environment. Because of operational difficulties encountered during the demonstration, a complete evaluation of the performance and cost characteristics of the NoVOCs™ technology could not be conducted. However, valuable information was collected regarding the operation and maintenance of the NoVOCs™ technology and site-specific factors that may influence the performance and cost of the system. This information may be useful to other decision-makers when carrying out specific remedial actions using this technology or conducting further technology performance evaluations. Data from the SITE evaluation may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Since the demonstration was stopped due to operational difficulties, only limited conclusions can be drawn from the field evaluation documented in this TER.

NoVOCs™ Technology Description

MACTEC's NoVOCs™ system is a patented in-well stripping process for in situ removal of VOCs from groundwater. In this process, air injected into a specially designed well simultaneously lifts groundwater, strips VOCs from the groundwater, and allows the groundwater to reinfiltrate into the aquifer. The NoVOCs™ system installed at NAS North Island consists of a well casing installed into the contaminated saturated zone, with two screened intervals below the water table, and an air injection line extending into the groundwater within the well. This NoVOCs™ well configuration is atypical; the recharge zone of most NoVOCs™ wells is located in the vadose zone. Contaminated groundwater enters the well through the lower screen and is pumped upward within the well by pressurized air supplied through the air injection line, creating an airlift pump effect. As the water is air-lifted within the well, dissolved VOCs in the water volatize into the air space at the air-water interface. The treated water rises to a deflector plate and is forced out of the upper screen. The treated water is then recharged to the aquifer, and the stripped VOC vapors are removed by a vacuum applied to the upper well casing. At NAS North Island, the stripped vapors were then treated by the Thermatrix flameless oxidation process. Other offgas treatment systems can be used with the NoVOCs™ technology, and the Thermatrix system is not an integral part of the NoVOCs™ treatment system. The equipment used to operate the NoVOCs™ system, including blowers, control panel, and air temperature, pressure, and flow rate gauges, is housed in an on-site control trailer.

Evaluation Objectives and Approach

The SITE evaluation of the NoVOCs™ technology was designed with three primary and seven secondary objectives to provide potential users of the technology with the information necessary to assess the performance of the NoVOCs™ system. The following primary and secondary objectives were selected to evaluate the technologies:

Primary Objectives:

- **P1** Evaluate the removal efficiency of the NoVOCs™ well system for VOCs in groundwater.
- **P2** Determine the radial extent of the NoVOCs™ treatment cell.

P3 Quantify the average monthly total VOC mass removed from groundwater treated by the system for 6 months.

Secondary Objectives:

S1 Quantify the changes in VOC concentrations in the groundwater within the NoVOCs™ treatment cell.

S2 Document changes in selected geochemical parameters that may be affected by the NoVOCs™ system.

S3 Document NoVOCs™ system operating parameters.

S4 Document pre- and post-treatment VOC concentrations and system operating parameters in the Thermatrix flameless oxidation offgas treatment system.

S5 Document the hydrogeologic characteristics at the treatment site.

S6 Document the changes in pressure head in the aquifer caused by the NoVOCs™ system.

S7 Estimate the capital and operating costs of constructing the NoVOCs™ system and Thermatrix flameless oxidation process and maintaining them for 6 months.

Because of operational difficulties with the NoVOCs™ system during the evaluation, not all objectives could be fully evaluated. Specifically, primary objectives P2 and P3 could not be fully evaluated. In these cases, results and conclusions are presented based on the available data.

The primary and secondary objectives were evaluated by collecting weekly and monthly samples from the groundwater and system offgas, as well as conducting a series of aquifer hydraulic tests. Samples were collected and analyzed using the methods and procedures presented in the Technology Evaluation Plan/Quality Assurance Project Plan for the MACTEC NoVOCs™ Technology Evaluation at NAS North Island (Tetra Tech 1998).

During the evaluation, groundwater samples were collected from the NoVOCs™ system influent and effluent using two piezometers installed adjacent to the NoVOCs™ well and from 10 groundwater monitoring wells installed upgradient, crossgradient, and downgradient of the NoVOCs™ well. The groundwater monitoring wells were installed at different depths and radii from the NoVOCs™ well to evaluate changes in contaminant concentrations within the aquifer associated with operation of the

NoVOCs™ system. Air samples were also collected from four sampling locations to evaluate the concentration of contaminants in the influent and effluent of both the NoVOCs™ and Thermatrix systems.

Operation and Maintenance

Operation and maintenance of the NoVOCs™ system was conducted primarily by Bechtel with technical guidance from MACTEC. The NoVOCs™ system was designed to operate continuously, 24 hours a day, 7 days a week. However, during the demonstration, the system experienced significant operational difficulties and was limited to four main operating periods: System Startup and Shakedown (February 26 through March 26, 1998), Early System Operation (April 20 through June 19, 1998), Reconfiguration Operation (September 24 through October 30, 1998), and Final Configuration Operation (December 4, 1998 through January 4, 1999).

Beginning in early May 1998, the NoVOCs™ system began experiencing operating problems associated with high water levels in the NoVOCs™ well and lower-than-designed pumping rates. Initially, it was thought that the flow sensor was not accurately measuring the pumping rate. However, as system operation progressed, the continued low pumping rate and increased frequency of the high water level in the NoVOCs™ well suggested that a more significant problem was occurring. By June 1998, the pumping rate had been reduced from the design rate of 25 gallons per minute (gpm) to about 5 gpm. Based on discussions between the Navy and MACTEC, the system was shut down on June 19, 1998, to evaluate the cause of the poor performance. Suspected causes for the poor performance included (1) biofouling or scaling of the screen intervals and formation near the NoVOCs™ well, (2) possible differences in hydraulic characteristic between the upper and lower portions of the aquifer, and (3) design problems with the NoVOCs™ well, in particular, the length of the recharge screen.

To evaluate the recharge capacity of the NoVOCs™ system and provide information on the hydraulic characteristics of the aquifer in the vicinity of the NoVOCs™ system, a down-well video tape survey and a series of aquifer hydraulic tests were conducted. Based on the aquifer testing, it was concluded that the length of the screened intervals of the NoVOCs™ well should be able to sustain the design pumping rate of 25 gpm. However, during the video tape survey, fouling of the NoVOCs™ well screens by microbiological growth and iron precipitation was observed, which appeared to have impaired the performance of the NoVOCs™ system by obstructing the well screen and filter pack. Attempts to control fouling by addition of various acids, dispersants, and biocides were unsuccessful, and failure to control the fouling eventually caused termination of the demonstration in January 1999.

Based on the results of the SITE evaluation at NAS North Island and other recirculating well evaluations, well fouling is a recognized problem that requires an appropriate design, as well as monitoring, operation, and maintenance for successful management. Groundwater wells, including in-well stripping systems and recirculating wells, such as the NoVOCs™ system, are subject to fouling from a variety of common causes. The three most common causes of fouling in recirculating wells and groundwater wells in general are (1) accumulation of silt in the well structure, (2) biofouling by colonizing microorganisms, and (3) formation of chemical precipitates or insoluble mineral species. These issues can sometimes be controlled through appropriate design and construction of filter pack and well screens, groundwater pH control to manage formation of chemical precipitates and insoluble mineral species, and injection of a suitable biocide to prevent biofouling. However, any design that does not provide geochemical controls based on site-specific hydrogeologic and geochemical conditions is likely to experience significant operation and maintenance problems due to fouling.

Evaluation Conclusions

Because of operational difficulties with the NoVOCs™ system throughout the demonstration, only limited data were collected to evaluate the technology. Based on the results of the limited data collected during the SITE evaluation, the following conclusions may be drawn about the applicability of the NoVOCs™ technology:

P1 Comparison of VOC results for groundwater samples taken adjacent to the influent and effluent of the NoVOCs™ system indicated that 1,1-DCE, cis-1,2-DCE, and TCE concentrations were reduced by greater than 98, 95, and 93 percent, respectively, in all the events, except the first sampling event, which was conducted during system shakedown activities. Excluding the first sampling event, the mean concentration of 1,1-DCE, cis-1,2-DCE, and TCE in the water discharged from the NoVOCs™ system was about 27, 1,400, and 32 micrograms per liter (Fg/L), respectively. The 95 percent upper confidence limits of the means for 1,1-DCE, cis-1,2-DCE, and TCE in the treated groundwater were calculated to be about 37, 1,760, and 46 Fg/L, respectively. The maximum contaminant levels (MCL) for these compounds in groundwater are 6 Fg/L for 1,1-DCE, 6 Fg/L for cis-1,2-DCE, and 5 Fg/L for TCE. MACTEC claims that the NoVOCs™ system can reduce effluent VOC concentrations to below MCLs if the contaminant source has been removed. Since dense nonaqueous-phase liquids may be present in the aquifer at the site and may act as a continuing source of groundwater contamination, MACTEC did not make any claims for reduction of VOC concentrations in groundwater at Site 9.

P2 Because of the sporadic operation of the NoVOCs™ system, a direct evaluation of the radial extent of the NoVOCs™ treatment cell was not conducted. In lieu of direct evaluation method, aquifer hydraulic tests conducted to assess the hydrogeologic characteristics of the site were used to indirectly evaluate the potential radial extent of the NoVOCs™ treatment cell. Although the aquifer pump tests cannot be directly applied to evaluate the radial extent of the NoVOCs™ treatment cell or even that groundwater recirculation was established, the test data does provide information on the radius of influence of the well under pumping (2-dimensional) and dipole (3-dimensional) flow conditions. The resulting changes in pressure head provide an indication of the potential for flow in the surrounding aquifer and are used to provide an estimate of the radial extent of influence created by the NoVOCs™ well. However, the pressure head changes do not accurately represent flow patterns or contaminant transport. Consequently no firm conclusions can be drawn about the radial extent of the NoVOCs™ treatment cell.

During the constant discharge rate (discharge = 20 gpm) pumping test, measurable drawdowns were observed at about 100 feet from the NoVOCs™ well in all directions and different depths. This information indicates that the radius of influence by extraction, specifically at 20 gpm, could be as large as 100 feet. The dipole flow test data shows that measurable pressure responses occur at crossgradient locations 30 feet from the NoVOCs™ well and may be observed at farther distances. However, no drawdowns or water level rises could be positively measured in monitoring wells beyond the 30-foot distance.

P3 Because of operational problems with the NoVOCs™ system, the mass of VOCs removed by the NoVOCs™ system was evaluated during a limited period of operation from April 28 to June 8, 1998. During this period, the average total VOC mass removed by the NoVOCs™ system ranged from 0.01 to 0.14 pounds per hour (lb/hr) and averaged 0.10 lb/hr during the five sampling events. Accounting for the sporadic operation of the NoVOCs™ system, the mass of total VOCs removed during the entire operation period from April 20 through June 19, 1998, was estimated to be about 90 pounds.

S1 VOC concentrations appear to be stratified in the aquifer. In general, the highest concentrations of the three primary VOCs, 1,1-DCE, cis-1,2-DCE, and TCE, were detected in the deep monitoring wells. This trend was especially pronounced for cis-1,2-DCE, which was detected at concentrations between 440 and 96,000 Fg/L in the deep wells, but only between 120 and 1,200 Fg/L in the shallow wells. The intermediate wells generally had the lowest concentration of all three primary VOCs. Because of the limited amount of data collected and operational problems with the NoVOCs™ system throughout the demonstration, trends in the VOC concentration data associated with operation of the NoVOCs™ system were not apparent.

S2 Groundwater samples were collected and analyzed for dissolved metals, alkalinity, total organic carbon, and dissolved organic carbon to evaluate changes in the selected geochemical parameters caused by the NoVOCs™ system. Despite the possible iron fouling problems experienced in the NoVOCs™ well, the groundwater analytical results for dissolved metals exhibited no clear trends in the data that would suggest that precipitation of dissolved metals was occurring in the aquifer. Based on a review of the data, alkalinity, total organic carbon, and dissolved organic carbon results remained relatively unchanged during the demonstration. Total dissolved solid concentrations showed an increasing trend with depth; however, concentrations did not appear to be affected by operation of the NoVOCs™ system. Conductivity and salinity values measured in the field also increased with depth and appeared to correlate with the analytical results for total dissolved solids. No clear trends were apparent from the field measurements of temperature, pH, and dissolved oxygen, and insufficient data were collected to adequately evaluate trends associated with oxidation/reduction potential.

S3 During the four operational periods, Bechtel measured the NoVOCs™ system operating parameters, including air temperature, pressure, flow rate, water pumping rate, and pH in the groundwater effluent. The average air temperature at the well intake during the four operational periods ranged from 132 to 152 ^{o}F; the pressure ranged from 2.2 to 3.3 pounds per square inch; and air flow ranged from 52.4 to 69.0 standard cubic feet per minute. The water pumping rate within the NoVOCs™ well varied throughout the demonstration; however, based on data provided by SWDIV, the pumping rate ranged from 8 to 34 gpm. Additionally, the average pH in the groundwater effluent during the four operational periods ranged from 3.60 to 7.28.

S4 Based on a comparison of influent and effluent air samples collected from the Thermatrix system, total VOC concentrations in the 1-hour composite samples collected from the influent ranged from 22,120 to 59,200 parts per billion (ppb) on a volume per volume (v/v) basis and averaged 45,200 ppb v/v during the five sampling events. Total VOC concentrations in the 1-hour composite samples collected from the effluent air sample port ranged from 2.8 to 7.2 ppb v/v and averaged 4.8 ppb v/v during the five sampling events. Total VOC concentrations measured in the Thermatrix influent air sample port were reduced by greater than 99.9 percent in all five sampling events.

S5 Based on the results of the hydrogeologic investigation conducted at the treatment site, the following hydrogeologic characteristics were estimated:

- Groundwater generally flows to the west or northwest in both of the upper and lower aquifer zones. The horizontal hydraulic gradient in both aquifer zones is relatively flat, ranging from 0.005 to 0.01. Groundwater direction and velocity measurements collected from the monitoring well near the shoreline of the San Diego Bay, using the Colloidal Borescope, indicate that groundwater flows in a west-southwest direction at an average of velocity of 5 feet per day (ft/day).

- The average hydraulic conductivity is 29 ft/day or 0.01 centimeters per second. The average aquifer storativity and specific yield are 0.004 and 0.07, respectively. The average ratio of horizontal to vertical hydraulic conductivity is 5.7.

- The calculated average specific capacities are 1.48 gallons per minute per foot (gpm/ft) for the upper screened interval during extraction, 1.50 gpm/ft for the upper screened interval during injection, and 3.22 gpm/ft for the lower screened interval during extraction. The calculated average well efficiencies are 82 percent for the upper screened interval during extraction, 97 percent for the upper screened interval during injection, and 91 percent for the lower screened interval during extraction.

- The radius of pressure influence (+/- 0.01 feet) during the constant discharge pumping test (20 gpm) is at least 100 feet, based on the drawdown measured at the observation wells.

- The maximum flow of clean tap water that can be injected through the upper screen of the NoVOCs™ well is 25 gpm.

- The aquifer hydraulic conditions do not limit application of the NoVOCs™ technology. The NoVOCs™ well as designed should be able to extract and inject a flow rate of 20 gpm, based on the estimated aquifer hydraulic characteristics.

S6 Pressure head changes in the aquifer caused by the NoVOCs™ system were measured in the groundwater monitoring wells in the vicinity of the NoVOCs™ system during a tidal study conducted at the treatment site before and during operation of the NoVOCs™ system. Groundwater level changes caused by startup and shutdown of the NoVOCs™ system were evident in the water level data for well cluster MW-45, MW-46, and MW-47, located about 30 feet from the NoVOCs™ well. The water level data for observation wells MW-45 (the upper screened well in this cluster) and MW-46 (the intermediate screened well) showed water level increases after system startup. The groundwater elevation increase in well MW-45 was approximately 0.15 feet. Observation well MW-46, the intermediate-depth well, showed a water level increase of approximately 0.05 feet. Observation well MW-47, the deep screened well, showed a water level decrease of approximately 0.025 feet. This pattern of water level increases and decreases associated with the operation of the NoVOCs™ system was expected, based on monitoring well screen locations relative to NoVOCs™ well screen locations. The deep screened well experienced a drop in water level as water was drawn toward the NoVOCs™ well intake, and the upper screened wells experienced increases in water level as water was lifted inside of the NoVOCs™ well and discharged into the upper aquifer zone. In well pair MW-48 and MW-49 (located about 62 feet from the NoVOCs™ well) and in wells MW-50 and MW-51 (located about 91 and 105 feet, respectively, from the NoVOCs™ well), water level changes associated with NoVOCs™ system operation were not apparent.

S7 An economic analysis of using the NoVOCs™ and Thermatrix technologies to treat VOC-contaminated groundwater and offgas was conducted. Based on the SITE evaluation and cost information provided by the Navy and MACTEC, one-time capital costs for a NoVOCs™ system were estimated to be $190,000; annual operation and maintenance costs were estimated to be $160,000 per year for the first year and $150,000 per year thereafter. Because of the time required to remediate an aquifer is site-specific, costs have been estimated for operation of a NoVOCs™ system over a range of time for comparison purposes. Based on these estimates, the total cost for operating a single NoVOCs™ system was calculated to be $350,000 for 1 year; $670,000 for 3 years; $1,000,000 for 5 years; and $2,000,000 for 10 years. These estimates include an annual inflation rate of 4 percent.

Costs for implementing a NoVOCs™ system at another site may vary substantially from this estimate for the SITE evaluation. A number of factors affect the cost of treatment using the

NoVOCs™ system, including soil type, contaminant type and concentration, depth to groundwater, site geology and hydrogeology, groundwater geochemistry, site size and accessibility, required support facilities and available utilities, type of offgas treatment unit used, and treatment goals. It is important to (1) characterize the site thoroughly before implementing this technology to ensure that treatment is focused on contaminated areas and (2) determine the circulation cell radius for the well and the resulting number of wells needed to remediate a particular site.

The cost of treatment per unit volume of water was not calculated because of the number of assumptions required to make such a calculation and the limited duration of system operation. Because of the site-specific nature of treatment costs, costs per unit volume of water will vary greatly from project to project.

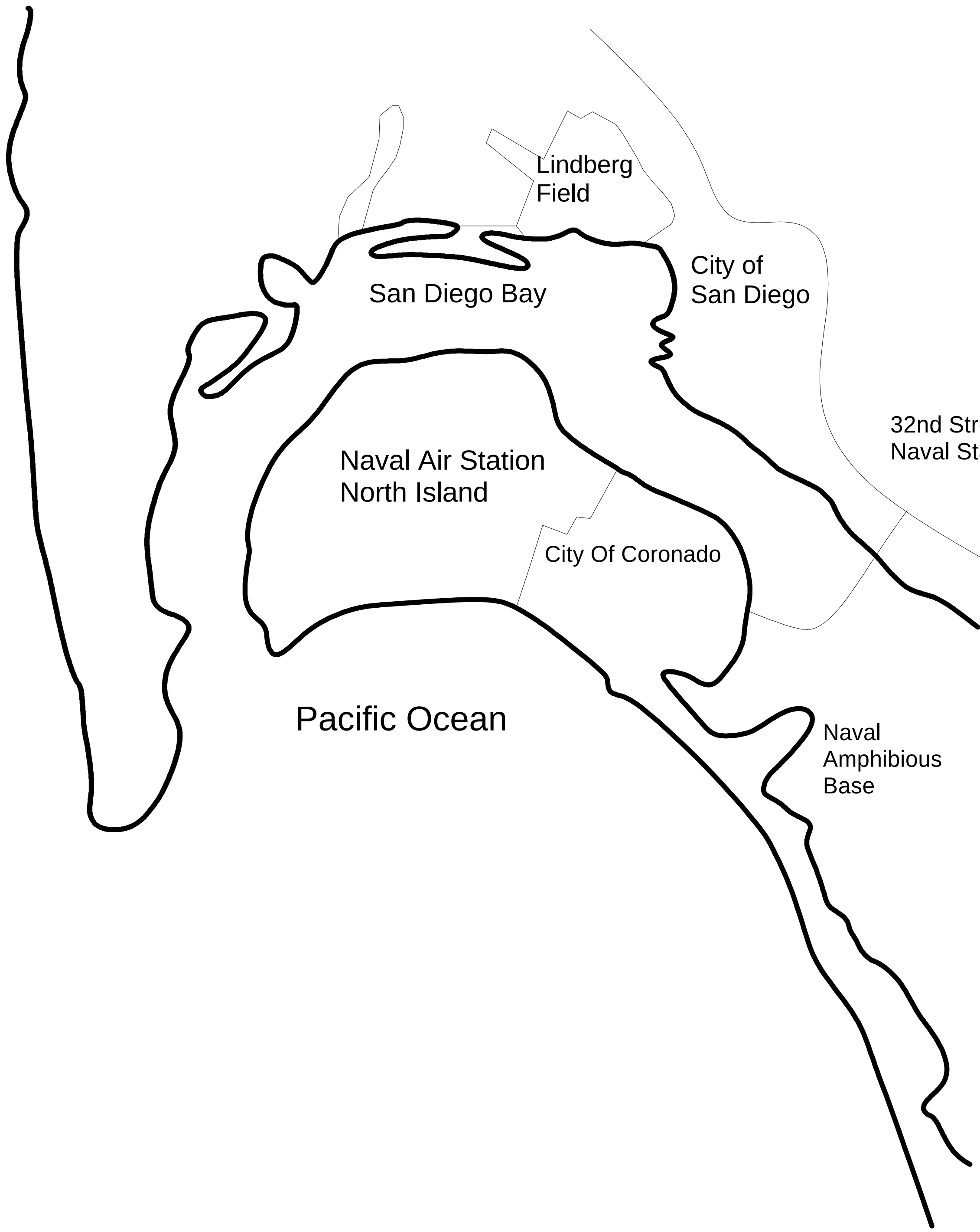
Based on cost information provided by SWDIV, the total cost of the Thermatrix system during the NoVOCs™ demonstration was about $989,000. This cost includes system acquisition, installation, operation, maintenance, monitoring, and source testing.

1.0 INTRODUCTION

This Technology Evaluation Report (TER) documents and summarizes the findings of an evaluation of the MACTEC, Inc. (MACTEC), NoVOCs™ in-well volatile organic compound (VOC) stripping system conducted by the U.S. Environmental Protection Agency (EPA), National Risk Management Research Laboratory (NRMRL) under the Superfund Innovative Technology Evaluation (SITE) Program. The report also includes performance data on the Thermatrix, Inc. (Thermatrix), flameless oxidation system, which was used to treat offgas from the NoVOCs™ system. The demonstration of the NoVOCs™ system was conducted at Installation Restoration (IR) Site 9 at the Naval Air Station (NAS) North Island in San Diego, California (see Figures 1, 2, and 3) to evaluate the technology's ability to treat VOC-contaminated groundwater. In addition to MACTEC and Thermatrix, the NoVOCs™ demonstration was conducted in partnership with the EPA Technology Innovation Office (TIO), Naval Facilities Engineering Command Southwest Division (SWDIV), Navy Environmental Leadership Program, and the innovative technology public-private partnership program facilitated by Clean Sites, Inc. (Clean Sites). Demonstration data collected by SWDIV and the vendor are included in this report.

Installation and operation of the NoVOCs™ system during the demonstration was conducted by SWDIV's support contractor, Bechtel National, Inc. (Bechtel). Tetra Tech EM Inc. (Tetra Tech) was the SITE Program contractor for the evaluation. This report documents the activities conducted during the demonstration and summarizes data collected by all involved parties.

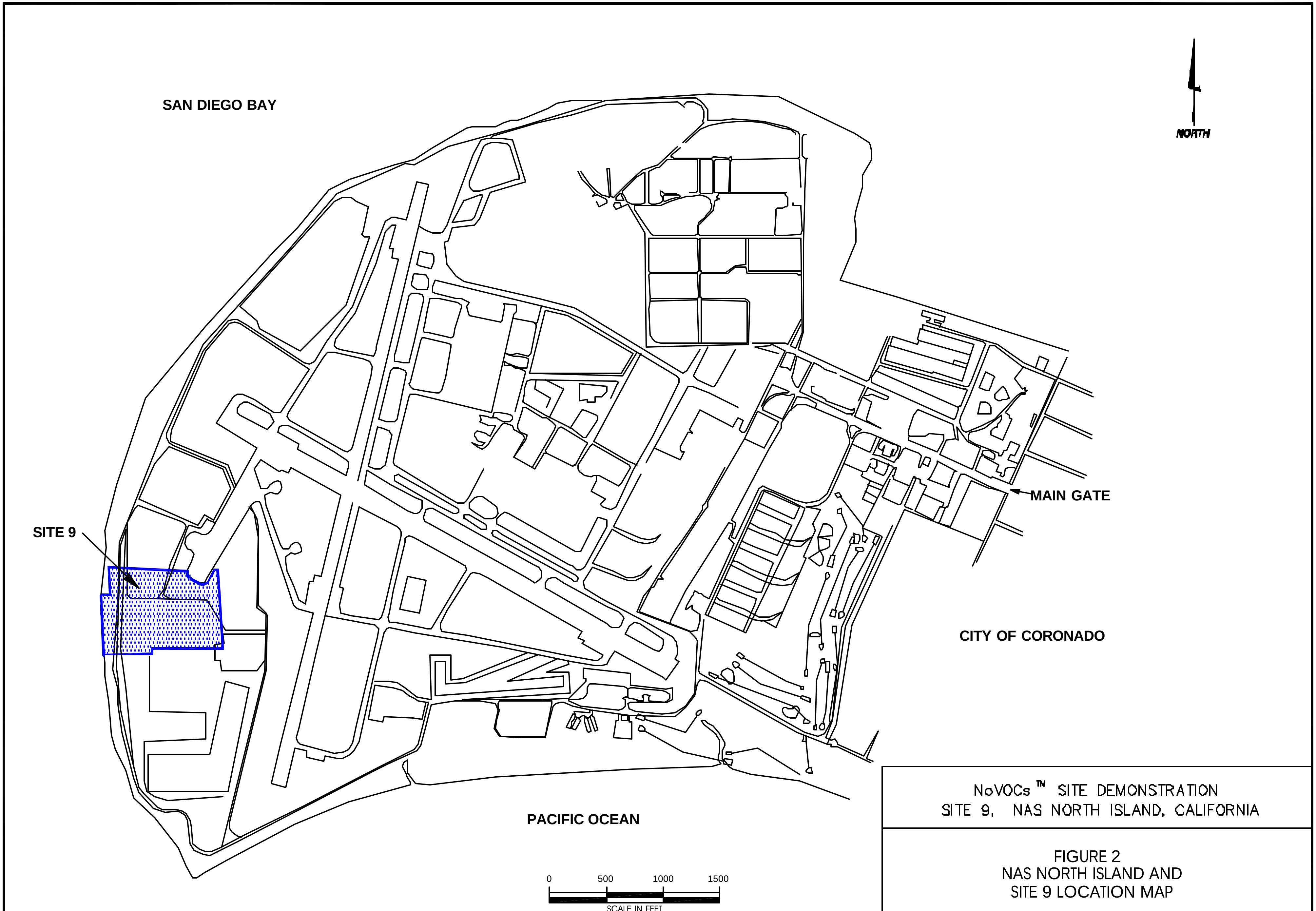
This TER provides information on the ability of the NoVOCs™ technology to treat groundwater contaminated with VOCs and includes a comprehensive description of the demonstration at NAS North Island and its results. Because of operational difficulties encountered during the demonstration, a thorough evaluation of the performance and cost characteristics of the NoVOCs™ technology's ability to treat VOC-contaminated groundwater could not be conducted. However, valuable information was collected regarding the operation and maintenance of the NoVOCs™ technology and site-specific factors that may influence system performance. This information may be useful to other decision-makers for consideration when carrying out specific remedial actions using this technology or conducting further technology performance evaluations. Data from the demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from this field demonstration.



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 1
VICINITY MAP

Tetra Tech EM Inc.

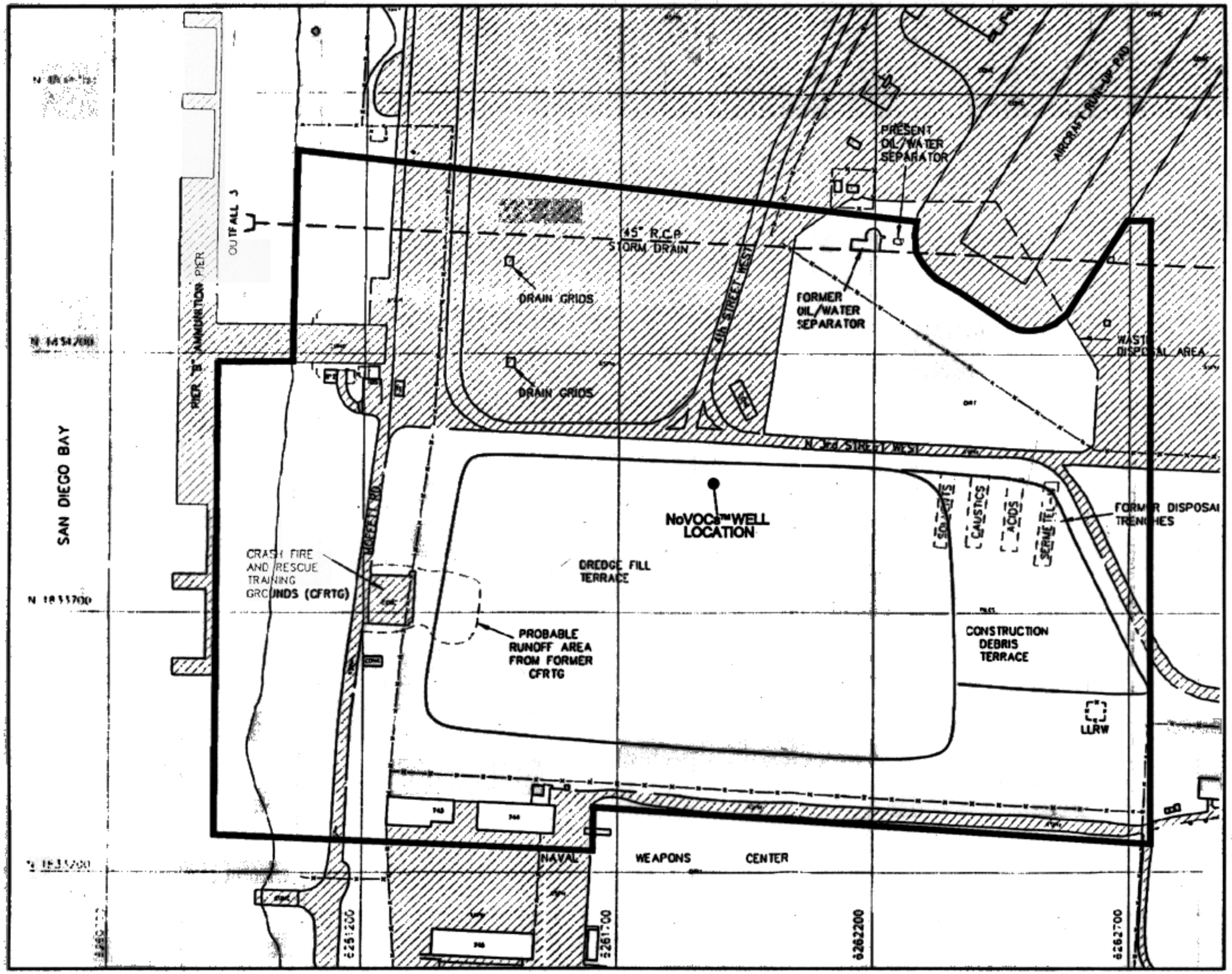


SOURCE: MODIFIED FROM BROWN AND CALDWELL 1983.

NoVOCs™ SITE DEMONSTRATION
SITE 9, NAS NORTH ISLAND, CALIFORNIA

FIGURE 2
NAS NORTH ISLAND AND
SITE 9 LOCATION MAP

Tetra Tech EM Inc.



LEGEND

FENCE

ROAD AND STREET

BUILDING

PAVEMENT (CONCRETE OR ASPHALT)

TERRACE BORDERS

LLRW — LOW-LEVEL RADIOACTIVE WASTE STORAGE AREA

STORM DRAIN

SITE 9 BOUNDARY

NOTES:

1. BASE MAP ADAPTED FROM PHOTGRAMMETRY BY BECHTEL NATIONAL, INC., 1994.
2. ELEVATION DATUM IS MEAN LOWER LOW WATER.
3. COORDINATES ARE IN THE CALIFORNIA COORDINATE SYSTEM (1983) ZONE 6 BASED ON THE NORTH AMERICAN DATUM (1983).

0 250 500

SCALE IN FEET

NOVOCs™ SITE DEMONSTRATION
SITE 9, NAS NORTH ISLAND, CALIFORNIA

FIGURE 3

SITE 9 CHEMICAL WASTE DISPOSAL AREAS

Tetra Tech EM Inc.

SOURCE: MODIFIED FROM JACOBS 1994

The TER is divided into seven sections. Section 1.0 presents the project background, SITE Program information, technology description, and key contacts. Section 2.0 describes the demonstration site, evaluation objectives, evaluation methods and procedures, and modifications to the NoVOCs™ demonstration Technology Evaluation Plan/Quality Assurance Project Plan (TEP/QAPP) (Tetra Tech 1998). Section 3.0 presents the results of measurements taken during the demonstration. Section 4.0 presents the technology economic analysis. Section 5.0 presents the conclusions of the evaluation, Section 6.0 discusses the technology status, and Section 7.0 includes a list of references.

The TER is appended by six sections, which are divided into six volumes. Appendix A—Auxiliary Tables and Graphs, Appendix B—Vendor Case Studies, and Appendix C—Hydrogeologic Investigation Results, are presented, along with the TER in Volume I. Appendix D—Laboratory Data, are presented in Volumes II through V. Appendix E—Field Data, and Appendix F—Quality Assurance and Quality Control Data Summary, are presented in Volume VI.

1.1 PROJECT BACKGROUND

As part of the feasibility study for the cleanup of the Chemical Waste Disposal Area (Site 9) at NAS North Island, SWDIV is conducting a series of pilot-scale treatability studies to obtain site-specific performance and cost data on potentially applicable remedial technologies to address soil and groundwater contamination at the site. During screening of applicable technologies, the NoVOCs™ technology was identified as a possible remedial solution to treat VOC-contaminated groundwater at Site 9. In addition, an innovative offgas treatment system, the Thermatrix flameless oxidation system, was selected to treat the offgas generated by the NoVOCs™ system. SWDIV, in cooperation with EPA TIO, Clean Sites, and the EPA SITE Program, began project planning of the NoVOCs™ and Thermatrix technology evaluation in 1995. Clean Sites also facilitated an Innovative Technology Public-Private Partnership that includes ICI, DuPont, and General Electric to provide technical review and input during the demonstration. Initiation of the NoVOCs™ demonstration was originally planned for 1997, but because of various regulatory, financial, and technical issues, implementation of the demonstration was delayed until 1998.

Based on site characterization information from Site 9, the initial design for the NoVOCs™ well prepared by EG&G Environmental (EG&G) included the extraction of groundwater from the lower portion of the aquifer and injection of treated water into the vadose zone through an infiltration gallery.

Installation of the NoVOCs™ well at NAS North Island began in October 1997. During advancement of soil borings, a silt layer was encountered at a depth that bisected the treatment zone. Because of concerns that the silt layer may act as a hydraulic barrier at the site and may adversely impact formation of a circulation cell, the location of the NoVOCs™ well was moved about 300 feet southeast, and the well configuration was redesigned.

Installation of the redesigned NoVOCs™ well at the second location began in January 1998. The redesigned well included extraction of groundwater from the lower portion of the aquifer and injection of treated groundwater in the saturation zone, just below the A silt/clay. Before installation of the redesigned well, the NoVOCs™ technology was sold by EG&G Environmental to MACTEC in December 1997. As a result of the sale, a new NoVOCs™ project team was brought in by MACTEC.

In February 1998, installation of the NoVOCs™ well was completed, and the NoVOCs™ technology began system startup and shakedown activities. Bechtel, the environmental support contractor for SWDIV, MACTEC, and Thermatrix managed the installation and operation of the NoVOCs™ well and the offgas treatment systems, with assistance from Gilbert Hill Associates and Umtanum Enterprises. The NoVOCs™ system was installed immediately downgradient from a contaminant source area to treat VOC-contaminated groundwater. Because of geologic conditions encountered during advancement of the NoVOCs™ well and associated monitoring wells, the NoVOCs™ well design was altered during installation to treat a portion of the aquifer instead of the entire aquifer.

On February 26, 1998, the NoVOCs™ system began startup and shakedown activities, which continued through March 9, 1998. On March 13, 1998, the system began continuous operation with only minor interruptions for system checks and balances. The NoVOCs™ system was shut down by MACTEC on March 26, 1998, because the pH control system did not send a high pH shutdown signal to the blower control system.

After MACTEC added a pH shutdown signal, the system was restarted on April 20, 1998. The EPA SITE Program evaluation of the NoVOCs™ system also began in April 1998 and included collection of air and groundwater samples from the NoVOCs™ system and surrounding monitoring points. The evaluation was conducted in accordance with the Technology Evaluation Plan/Quality Assurance Project Plan for the MACTEC NoVOCs™ Technology Evaluation at NAS North Island (Tetra Tech 1998). By June 1998, the pumping rate of the NoVOCs™ system had been reduced from the design rate of 25 gallons per minute (gpm) to about 5 gpm because injection rates above 5 gpm could not be maintained without the water level in the well rising. In addition, during this period, the system experienced numerous shutdowns because of high water levels in the NoVOCs™ well. Based on discussions between the Navy and the technology vendor, the system was shut down on June 19, 1998, to evaluate the cause of the system operating problems. Suspected causes included (1) biofouling or scaling of the screen intervals and formation near the NoVOCs™ system; (2) possible differences in hydraulic characteristics between the upper and lower portions of the aquifer; and (3) design problems with the NoVOCs™ well, in particular, the length of the recharge screen. The Site was particularly challenging because the groundwater contained total dissolved solids (TDS) concentrations ranging from 18,000 to 41,000 mg/L; a much higher TDS than in a typical drinking water aquifer.

To determine if the operating problems were caused by improper well design or aquifer conditions, a series of aquifer pump tests were conducted from July 27 through August 5, 1998. The pump tests provided information on the recharge capacity of the NoVOCs™ system and the aquifer hydraulic characteristics in the vicinity of the NoVOCs™ system. The hydrogeologic study included: (1) a tidal influence study to evaluate natural variations in water level at the site caused by tides in San Diego Bay, and (2) a series of groundwater pumping tests in the shallow and deep portions of the aquifer, including step drawdown tests, a 32-hour constant discharge pumping test, an injection test, and a dipole flow test to evaluate the aquifer characteristics in the vicinity of the NoVOCs™ system. A biofouling and scaling study was also conducted by the vendor.

Based on the results of these studies, it was determined that the initial well design would be modified to allow for more efficient air-water separation and a sequestering agent would be added to the system to minimize metal precipitation. Significant biological growth was noted during pump test activities, so it was decided that a periodic biocide treatment would also be added to the groundwater flowing through the system. The internal components of the NoVOCs™ well were redesigned by MACTEC and were installed in September 1998.

Operation of the redesigned NoVOCs™ system was initiated on September 24, 1998, using a modified chemical treatment, which consisted of acid and biocide injection into the influent piezometer to control the precipitation of iron and biological growth near the NoVOCs™ well. The redesigned system continued operation until October 29, 1998. During this period, the system continued to experience problems with high water levels in the NoVOCs™ well and was not able to operate for sustained periods of time. As a result of inconsistent operation, completion of planned evaluation activities, including the dye trace study and collection of groundwater and air samples to evaluate system performance, were postponed until satisfactory operating conditions could be achieved.

A project team meeting was held in San Diego, California, on November 9 and 10, 1998, to discuss system operating problems and continued evaluation of the NoVOCs™ system. At the meeting, MACTEC indicated that they were not willing to commit additional resources to making the NoVOCs™ system work at NAS North Island and withdrew from the demonstration. However, SWDIV decided to continue operation of the NoVOCs™ system and modified the chemical treatment used to control metal precipitation and biological growth in an effort to get the system operational and continue the evaluation of the system.

On December 4, 1998, the NoVOCs™ system was restarted. During operation of the NoVOCs™ system, the well was aggressively treated with hydrochloric acid, citric acid, bromide/chloride solution, and hydrogen peroxide to mitigate biofouling and precipitation of iron. However, even with aggressive chemical treatment, the system continued to experience operational shutdowns because of high water levels in the NoVOCs™ well. In addition, the Thermatrix system began to experience maintenance problems that also adversely affected operation of the NoVOCs™ system. Finally, on January 4, 1999, the NoVOCs™ demonstration was terminated by SWDIV because of continued operating problems associated with biofouling of the NoVOCs™ well.

1.2 THE SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION PROGRAM

The SITE Program was established by EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA). The SITE Program promotes the development, evaluation, and use of new or innovative technologies to clean up Superfund sites across the country.

The SITE Program's primary purpose is to maximize the use of alternatives in cleaning up hazardous waste sites by encouraging the development and evaluation of innovative treatment and monitoring technologies. It consists of three major elements:

- The Technology Evaluation Program
- The Monitoring and Measurement Technologies Program
- The Technology Transfer Program

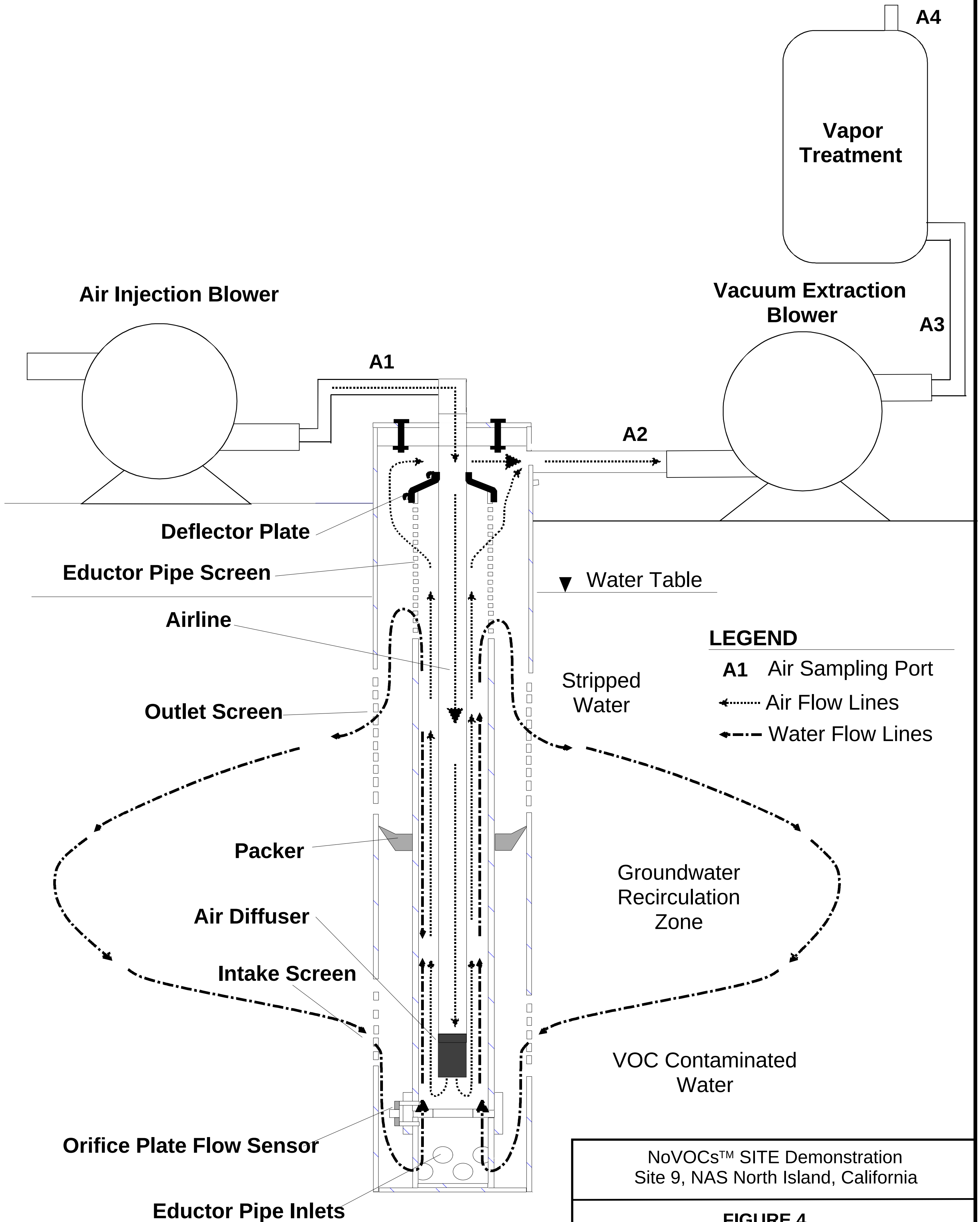
The objective of the Technology Evaluation Program is to develop reliable performance and cost data on innovative technologies so that potential users may assess the technology's site-specific applicability. Technologies evaluated are either currently available or close to being available for remediation of Superfund sites. SITE evaluations are conducted on hazardous waste sites under conditions that closely simulate full-scale remediation conditions, thus ensuring the usefulness and reliability of information collected. Data collected are used to assess: (1) the performance of the technology, (2) the potential need for pre- and post-treatment processing of wastes, (3) potential operating problems, and (4) approximate costs. The evaluations also allow for assessment of long-term risks.

Existing technologies that improve field monitoring and site characterizations are identified in the Monitoring and Measurement Technologies Program. New technologies that provide faster, more cost-effective contamination and site assessment data are supported by this program. The Monitoring and Measurement Technologies Program also formulates protocols and standard operating procedures for evaluation methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Evaluation and Monitoring and Measurements Technologies Programs through various activities. These activities increase the awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of technology transfer activities is to develop interactive communication among individuals requiring up-to-date technical information.

1.3 TECHNOLOGY DESCRIPTION

MACTEC’s NoVOCs™ system is a patented in-well stripping process (U.S. Patent No. 5,180,503) for in situ removal of VOCs from groundwater. A schematic of the treatment process is shown in Figure 4. In this process, air injected into a specially designed well simultaneously creates an airlift pump and an in situ stripping reactor to circulate and remediate groundwater (EG&G 1996).



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 4
NoVOCs™ SYSTEM

Tetra Tech EM Inc.

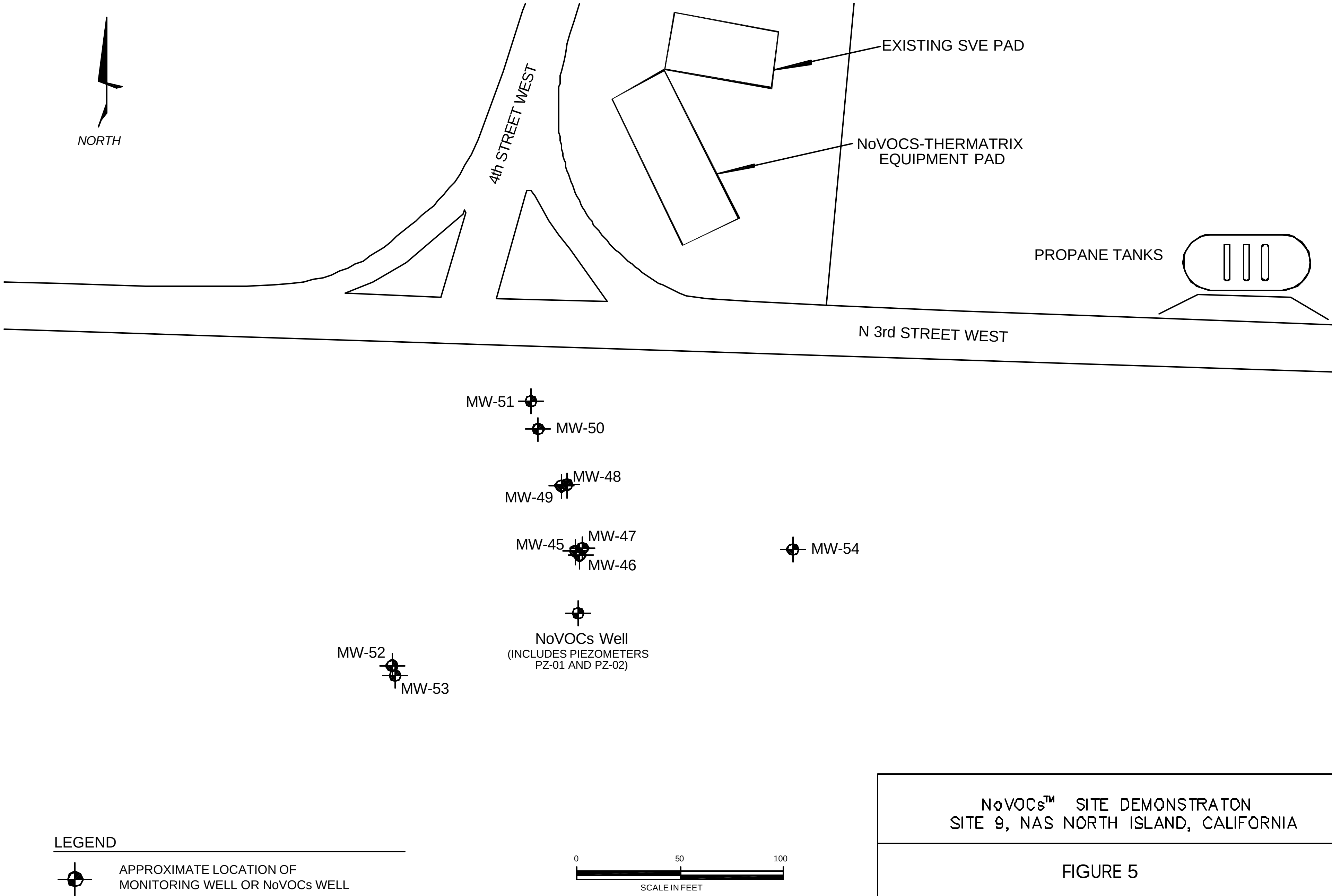
Not to scale

MODIFIED FROM MACTEC 1998

The NoVOCs™ system at NAS North Island consisted of a well casing installed in the contaminated saturated zone, with screened intervals below the water table and an air injection line extending into the groundwater within the well. Contaminated groundwater enters the well through the lower screen and is pumped upward within the well by pressurized air supplied through the air injection line, creating an air-lift pump effect. As the water is air-lifted within the well, dissolved VOCs in the water volatilize into the air space at the air-water interface. The treated water rises to a deflector plate and is forced out of the upper screen. Treated water is recharged to the aquifer, and stripped VOC vapors are removed from the subsurface by a vacuum applied to the upper well casing. At NAS North Island, the stripped vapors were treated by the Thermatrix flameless oxidation process (EG&GE 1996) and discharged to the atmosphere. Other open- and closed-loop offgas treatment systems can be used with the NoVOCs™ technology, and the Thermatrix system is not an integral part of the NoVOCs™ treatment system. The equipment used to operate the NoVOCs™ system, including blowers, control panel, and air temperature, pressure, and flow rate gauges, was housed in an on-site control trailer.

The NoVOCs™ well may be used to remediate contaminant source areas or as a groundwater interdiction system to prevent further migration of a contaminant plume. At NAS North Island, one NoVOCs™ well was installed to remediate a portion of the aquifer downgradient from a contaminant source area. Two piezometers and 10 monitoring wells were also installed to enable sample collection in support of the evaluation of the NoVOCs™ system. Figure 5 shows a plan view of the location of the NoVOCs™ system well and associated piezometers and monitoring wells. Figure 6 shows a generalized cross-section of the NoVOCs™ system well, piezometers, and crossgradient monitoring wells.

MACTEC claims that the NoVOCs™ system can reduce effluent groundwater VOC concentrations to below federal maximum contaminant levels (MCL) if the contaminant source has been removed. Because dense nonaqueous-phase liquids (DNAPL) may be present in the aquifer at this evaluation site and may act as a continuing source of groundwater contamination, MACTEC did not make any claims for the reduction of dissolved VOC concentrations in groundwater at Site 9. Given the designed pumping rate of 25 gpm and a total air flow rate of 120 standard cubic feet per minute (scfm), MACTEC estimated that the effective radius of the circulation cell established by the NoVOCs™ system at this site would be at least 90 feet (EG&GE 1997). In addition, the vendor claimed that the NoVOCs™ system would remove more than 80 percent of the VOCs that pass through the system.

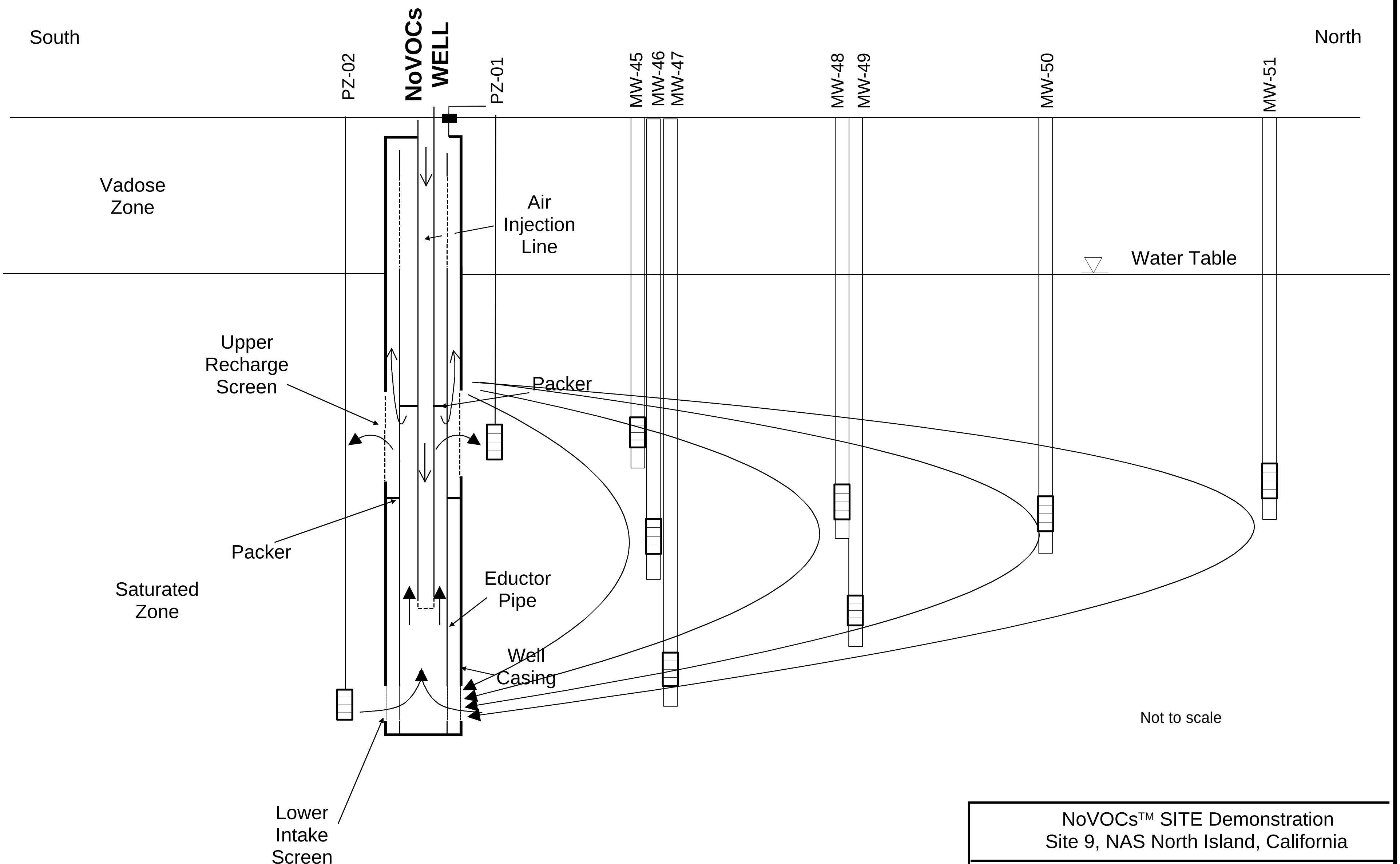


NoVOCs™ SITE DEMONSTRATON
SITE 9, NAS NORTH ISLAND, CALIFORNIA

FIGURE 5

WELL LOCATIONS

Tetra Tech EM Inc.



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 6
GENERALIZED CROSS-SECTION

Tetra Tech EM Inc.

1.4 KEY CONTACTS

Additional information on the SITE Program and the evaluation can be obtained from the NRMRL Project Manager:

- Michelle Simon, P.E.
  U.S. Environmental Protection Agency
  Office of Research and Development
  26 West Martin Luther King Drive
  Cincinnati, Ohio 45268
  Telephone: (513) 569-7469, Facsimile: (513) 569-7676
  E-mail: simon.michelle@epa.gov

Additional information on the NoVOCs™ technology or the evaluation can be obtained from the technology vendor:

- Warren Schultz
  MACTEC, Inc.
  1819 Denver West Drive, Suite 400
  Golden, Colorado 80401
  Telephone: (303) 278-3100, Facsimile: (303) 273-5000
  E-mail: wschultz@maccorp.com

In addition, information on the SITE Program is available through the following on-line information clearinghouses:

- SITE Program Home Page: http://www.epa.gov/ORD/SITE

- The Alternative Treatment Technology Information Center (ATTIC) Internet Access: http://www.epa.gov/attic

- Cleanup Information Bulletin Board System (CLU-IN)
  Help Desk: (301) 589-8368; Internet Access: http://www.clu-in.org

- EPA Remediation and Characterization Innovative Technologies
  Internet Access: http://www.epa.reachit.org

- Groundwater Remediation Technology Center
  Internet Access: http://www.gwrtac.org

Technical reports may be obtained by contacting the National Service Center for Environmental Publications (NSCEP) in Cincinnati, Ohio. To find out about newly published documents or to be placed on the SITE mailing list, call or write to:

C U.S. EPA/NSCEP
P.O. Box 42419
Cincinnati, OH 45242-2419
(800) 490-9198

2.0 SITE DESCRIPTION, OBJECTIVES, AND PROCEDURES

Demonstration site background, objectives, and methods and procedures for the NoVOCs™ technology evaluation are described in the following sections.

2.1 DEMONSTRATION SITE DESCRIPTION

This section provides information on site conditions, including site history, topography, geology, hydrogeology, and soil and groundwater contamination at NAS North Island and Site 9.

2.1.1 Site History

NAS North Island is the largest naval aviation complex on the West Coast and is home to three aircraft carriers and the Third Fleet flagship, USS Coronado. NAS North Island is located at the northern end of the peninsula that forms San Diego Bay and is bordered by the City of Coronado to the east, the Pacific Ocean to the south, and San Diego Bay to the north and west (see Figure 1). The 2,806-acre complex, officially commissioned in 1917, provides aviation support services to the fleet, aircraft maintenance, airfield operations, pierside services, and logistics. The mission of NAS North Island is to maintain and operate facilities and to provide services and material that support operation of aviation activities and units of the Operating Forces of the Navy, as well as other units, as designated by the Chief of Naval Operations.

Past hazardous waste disposal practices at NAS North Island have resulted in soil and groundwater contamination. The Navy has undertaken investigations to determine the extent of contamination and possible cleanup methods as part of the IR Program. Under the IR Program, 14 contaminated areas have been designated IR sites, one of which is Site 9 (see Figure 2).

Site 9, the 40-acre former chemical waste disposal area, is located on the western end of NAS North Island. Site 9 operated from the 1940s to the mid-1970s and consisted of three major waste disposal areas: a shallow pit used for disposal of liquid wastes (located within the waste disposal area shown in Figure 3); four parallel trenches, each containing different types of wastes (solvents, caustics, acids, and semisynthetics consisting of ceramic and metallic compounds); and a large unimproved area used for burying drums containing unidentified chemical wastes, located south of the NoVOCs™ well. An estimated 8 to 24 million gallons of waste were disposed of at Site 9 over its 30 years of operation (Jacobs 1995a).

Contamination from these disposal areas has migrated to the underlying groundwater. Although no official history of chemical disposal exists for most of Site 9 outside of the three disposal areas, groundwater contamination is widespread throughout the site. Elevated levels of chlorinated solvents and their breakdown products, as well as petroleum hydrocarbons and metals, are present in groundwater at Site 9. Based on the high dissolved concentrations of chlorinated solvent compounds, the presence of DNAPL in the subsurface is suspected (Jacobs 1995a).

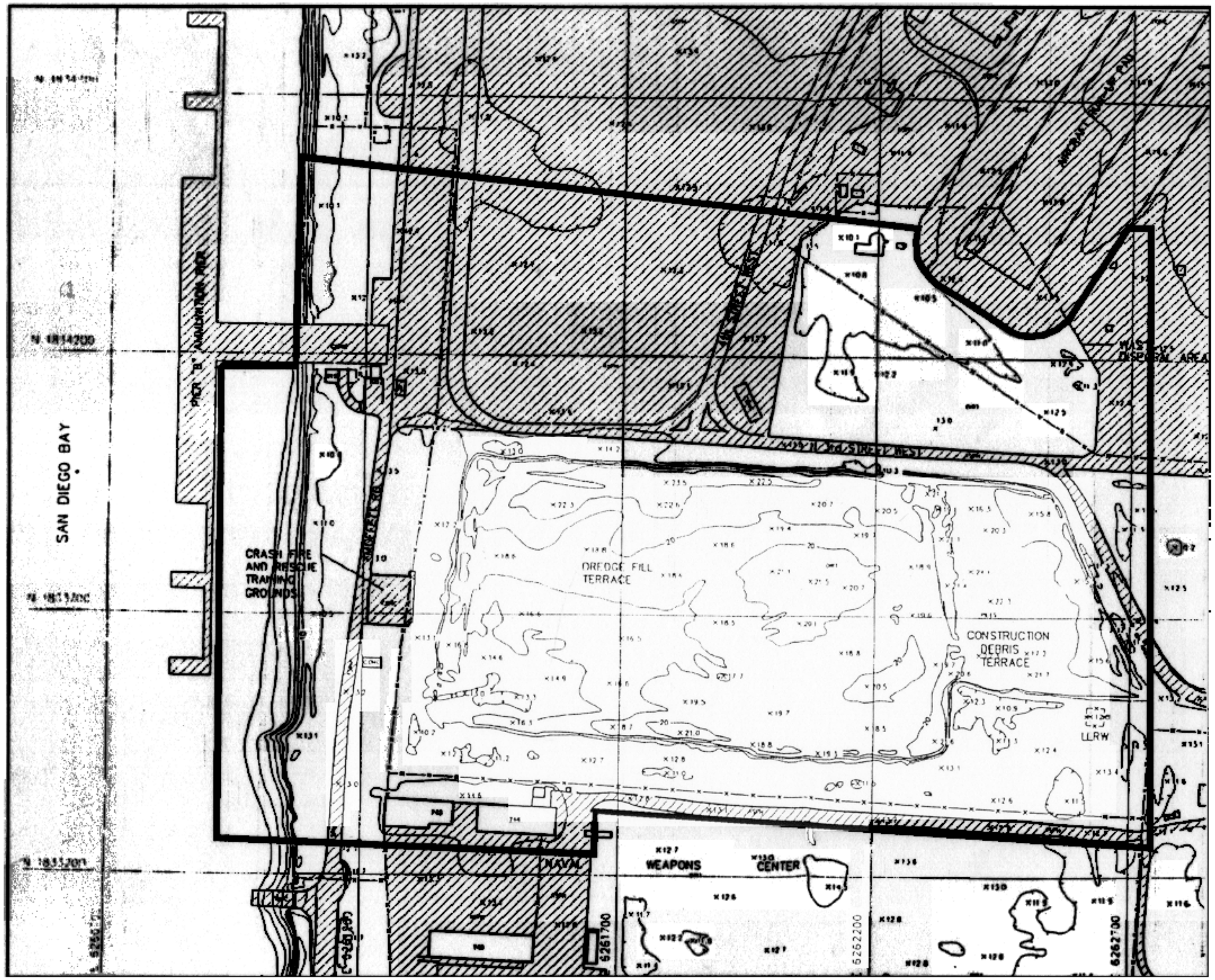
The Navy selected a location immediately south of the intersection of 4th Street West and North 3rd Street West to install the NoVOCs™ system (see Figure 3). Cone penetrometer test (CPT) boreholes advanced at the proposed NoVOCs™ location provided additional characterization of subsurface lithology and confirmed that significant groundwater contamination was present (Bechtel 1998).

2.1.2 Site Topography

The topography of the northern half of Site 9 is relatively flat with an elevation of about 13 feet above mean lower low water (MLLW). It has virtually no relief and is covered by asphalt paving. The southern half of the site is unpaved and is almost entirely covered by a terrace composed of hydraulic dredge spoils. The terrace has an elevation of about 23 feet above MLLW along its northern face and slopes gently southward to about 18 feet above MLLW (Jacobs 1994). Topographic elevations and surface features are shown in Figure 7. The NoVOCs™ well was installed on the terrace at a surface elevation of about 22 to 23 feet above MLLW.

2.1.3 Regional and Site Geology

This section discusses the regional and site geology for Site 9.



LEGEND

CONTOUR LINE

FENCE

ROAD AND STREET

BUILDING

X 12.3 SPOT ELEVATION

PAVEMENT (CONCRETE OR ASPHALT)

LLRW LOW-LEVEL RADIOACTIVE WASTE STORAGE AREA

SITE 9 BOUNDARY

NOTES:

1. BASE MAP ADAPTED FROM PHOTGRAMMETRY BY BECHTEL NATIONAL, INC., 1994.
2. ELEVATION DATUM IS MEAN LOWER LOW WATER.
3. COORDINATES ARE IN THE CALIFORNIA COORDINATE SYSTEM (1983) ZONE 6 BASED ON THE NORTH AMERICAN DATUM (1983).

0 250 500
SCALE IN FEET

NOVOCs™ SITE DEMONSTRATION
SITE 9, NAS NORTH ISLAND, CALIFORNIA

FIGURE 7

SITE 9 TOPOGRAPHIC ELEVATIONS

Tetra Tech EM Inc.

SOURCE: MODIFIED FROM JACOBS 1994

2.1.3.1 Regional Geology

NAS North Island is situated in the coastal portion of the Peninsular Range Geomorphic Province. This region is underlain by a basement complex of late Cretaceous undifferentiated igneous rocks of the Southern California Batholith and Jurassic prebatholithic metavolcanic rocks. The basement complex is nonconformably overlain by a sedimentary succession of marine and nonmarine rocks that were deposited within the San Diego embayment. These rocks range in age from Late Cretaceous to Recent. The most abundant deposits of the embayment are gently folded and faulted Eocene marine, lagoonal, and nonmarine rocks that thin eastward and trend northwest (Jacobs 1995b).

2.1.3.2 Site Geology

Site 9 is underlain by artificial fill to a depth of about 15 feet below ground surface (bgs) in the vicinity of the NoVOCs™ well. The artificial fill in this area varies in thickness. The terrace in the southern portion of the site is composed of hydraulic fill derived from dredging the San Diego Bay and consists of fine-grained, loose sand. In addition, in the immediate vicinity of the site, the former Whaler’s Bight, a shallow lagoon formerly present at the western edge of North Island, was filled with sediments during the early part of the twentieth century. Below the fill material is the Bay Point Formation, a poorly consolidated, fine- and medium-grained fossiliferous sandstone (Kennedy 1975).

The depositional environment of the Bay Point Formation at the site was lagoonal and shallow marine. Sediment accumulated on the southern portion of North Island generally from northward transport of sediment along the shore. As described below, most of the uppermost sediments at the site are composed of fine-grained sand, with varying amounts of silt and medium-grained sand. Two thin silt and clay layers are present in the subsurface at the site and are likely to be continuous in the vicinity of the site, based on observations in the numerous borings and wells installed at the site (Bechtel 1998).

The first fine-grained layer is a thin (2-to 5-feet-thick) clay, silt, and clayey sand layer designated as A clay/silt (Jacobs 1994). The A clay/silt occurs at about 35 to 40 feet bgs and is present beneath Site 9 (Jacobs 1994). Recent investigations by Bechtel have indicated that the A clay/silt is continuous from the proposed NoVOCs™ well locations west to the shoreline wells. Beneath the unconsolidated sediments is a sandstone layer at about 90 feet bgs. The second layer is the B clay, located about 105 feet bgs, that also appears to be continuous in the vicinity of the site. The location of a geologic cross-section is shown in Figure 8, and the cross-section depicting the subsurface geology of the site is shown in Figure 9.

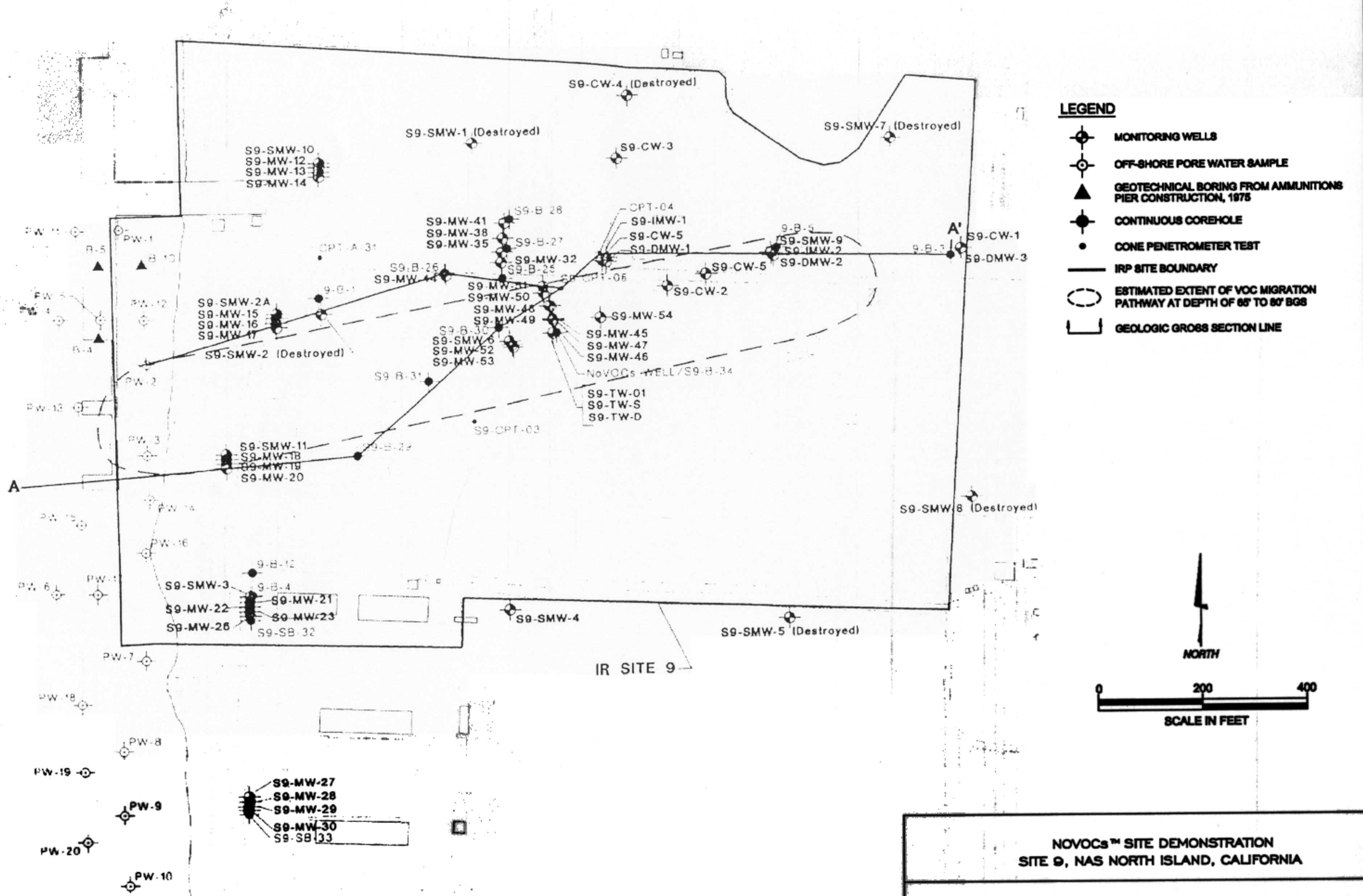
Boring S9-SB-34 located near the NoVOCs™ well encountered mostly sand and silty sand. The A clay/silt layer was encountered at 35.5 feet bgs, dense sands were encountered between 60 and 61 feet bgs and 65 to 67.5 feet bgs, and a thin, cemented sandstone layer was encountered at 79 feet bgs. In addition, the sand fractions of the sands and silty sands ranged from very fine- to coarse-grained and contained various quantities of shell fragments. The log for boring S9-SB-34 is provided in Volume VI, Appendix E.

2.1.4 Site Hydrogeology

The generally accepted hydrogeologic conceptual model for islands and peninsulas surrounded by salt water is a lens-shaped body of fresh water resting isostatically atop saltwater because of density differences. At Site 9, groundwater occurs at about 8 feet bgs (5 feet above MLLW). The upper 110 feet of the saturated zone contains an unconfined aquifer with a thin (5 to 20 feet), discontinuous freshwater lens, a brackish mixing zone (30 to 100 feet), and a saltwater wedge intruding inland. The reported values for some of the hydrogeological parameters of the site are as follows (Jacobs 1995b):

- Hydraulic Gradient: 0.0008 foot per foot (ft/ft) over most of the site, but steepens near the shoreline to 0.006 ft/ft
- Transmissivity: 1,195 square feet per day (ft^2/day)
- Specific Yield: 3.2×10^{-1} (dimensionless)
- Hydraulic Conductivity: 12 feet per day (ft/day) or 4.2×10^{-3} centimeters per second (cm/sec)
- Effective Porosity: 0.25 (dimensionless)

These were the hydrogeologic parameters used to design the NoVOCs™ well installed at NAS North Island. The possibility that the A clay/silt layer posed a hydraulic barrier to effective groundwater



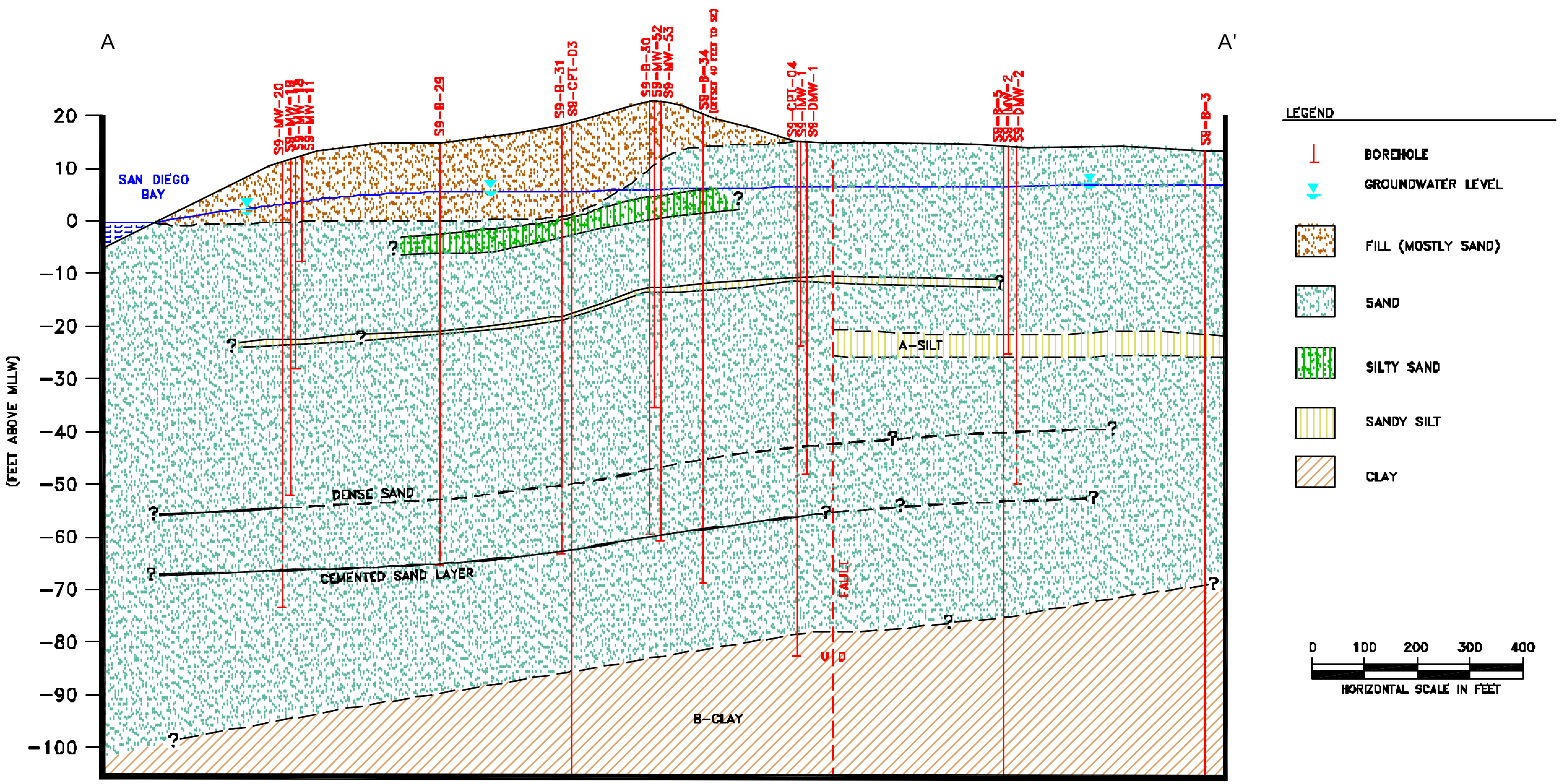
NOVOCs™ SITE DEMONSTRATION
SITE 9, NAS NORTH ISLAND, CALIFORNIA

FIGURE 8

GEOLOGIC CROSS-SECTION LOCATION

Tetra Tech EM Inc.

SOURCE: MODIFIED FROM BECHTEL (1998)



NaVOCs™ SITE DEMONSTRATION
SITE 9, NAS NORTH ISLAND, CALIFORNIA

FIGURE 9

GEOLOGIC CROSS SECTION A-A'

Tetra Tech EM Inc.

SOURCE: MODIFIED FROM BECHTEL 1998.

circulation also impacted the design of the well and resulted in an installation with both extraction and recharge occurring in the saturated zone under the A clay/silt.

In general, the hydraulic gradient is toward the west, varying between southwest and northwest and is tidally influenced. The distribution of groundwater contamination also suggests that the general flow of groundwater is toward the west. Contaminants associated with the site have been detected in pore water of San Diego Bay, west of Site 9 (SPAWAR Systems Center 1998). A survey of pore water concentrations of VOCs was conducted in the spring of 1998 in the upper 5 feet of sediment adjacent to and west of Site 9. The results of the survey documented that VOCs were present in the pore water at depths of about 20 to 30 feet below MLLW. The data suggest that contaminants are migrating west from Site 9, at a depth consistent with the A clay/silt layer, and discharging to the bay through pore water interchange with the bay water (Bechtel 1998).

2.1.5 Soil and Groundwater Contamination

Groundwater at NAS North Island is saline, with concentrations ranging from 18,000 to 41,000 mg/L. Based on findings from previous investigations at the site (Jacobs 1995a, 1995b), high concentrations of chlorinated solvents, chlorinated solvent breakdown products, petroleum hydrocarbons, and metals are present in the saturated and unsaturated zones. The major contaminants detected in groundwater are chlorinated aliphatic hydrocarbon solvents (tetrachloroethene [PCE], trichloroethene [TCE], and 1,1,1-trichloroethane) and their breakdown products (dichloroethane, dichloroethene [DCE], and vinyl chloride); lower concentrations of aromatic hydrocarbons (benzene, toluene, ethylbenzene, and xylenes [BTEX]); and heavy metals. Because of the high concentrations of chlorinated solvent compounds in groundwater above the B clay, DNAPL occurrences are suspected at several locations beneath Site 9. If present, DNAPL may act as a long-term source of dissolved-phase contamination in the unconfined aquifer.

Contaminants in soils consist of heavy metals, VOCs, and semivolatile organic compounds (SVOC). Eighteen priority pollutant VOCs have been detected in soil samples with individual compound concentrations of up to 3,600 milligrams per kilogram (mg/kg). Fourteen priority pollutant SVOCs, including polynuclear aromatic hydrocarbons (PAH), have been detected in soil samples with individual compound concentrations up to 1,668 mg/kg. In the former release areas, soils reportedly are virtually saturated with VOCs (Jacobs 1995a). In addition, large quantities of VOCs are believed to have evaporated from saturated soils and groundwater into the vadose zone. Elevated levels of TCE, PCE, and toluene have been detected in soil gas within the vadose zone (Jacobs 1995a).

2.2 EVALUATION OBJECTIVES

The SITE evaluation was designed to address primary and secondary objectives selected for the NoVOCs™ technology. These objectives were selected to provide potential users of the NoVOCs™ technology with the necessary technical information to assess the performance of the treatment system. For the SITE evaluation of the NoVOCs™ technology, three primary and seven secondary objectives were selected and are summarized below:

Primary Objectives:

P1 Evaluate the removal efficiency of the NoVOCs™ well system for VOCs in groundwater.

P2 Determine the radial extent of the NoVOCs™ treatment cell.

P3 Quantify the average monthly total VOC mass removed from groundwater treated by the system for 6 months.

Secondary Objectives:

S1 Quantify the changes in VOC concentrations in the groundwater within the NoVOCs™ treatment cell.

S2 Document changes in selected geochemical parameters that may be affected by the NoVOCs™ system.

S3 Document NoVOCs™ system operating parameters.

S4 Document pre- and post-treatment VOC concentrations and system operating parameters in the Thermatrix flameless oxidation offgas treatment system.

S5 Document the hydrogeologic characteristics at the treatment site.

S6 Document the changes in pressure head in the aquifer caused by the NoVOCs™ system.

S7 Estimate the capital and operating costs of constructing the NoVOCs™ system and Thermatrix flameless oxidation process and maintaining them for 6 months.

The objectives were evaluated by collecting weekly and monthly samples from the groundwater and system offgas, as well as conducting a series of pump tests. To meet the evaluation objectives, data were collected and analyzed using the methods and procedures summarized in Section 2.3.

2.3 EVALUATION METHODS AND PROCEDURES

This section describes the methods and procedures used to collect and analyze samples for the SITE evaluation of the NoVOCs™ technology. Field and analytical methods used to collect and analyze samples were as outlined in Sections 2.3.2, 2.3.3., and 2.3.4. Activities associated with the NoVOCs™ SITE evaluation included (1) field equipment installation, (2) evaluation design, (3) groundwater and soil gas sample collection and analysis, and (4) field and laboratory quality assurance and quality control (QA/QC).

2.3.1 Field Equipment Installation

Predemonstration activities conducted by SWDIV's support contractor, Bechtel, included (1) advancement of a CPT and collection of groundwater samples to evaluate the geology and contaminant distribution at the demonstration site, (2) continuous coring and installation of the NoVOCs™ well and two adjacent piezometers, and (3) the drilling of 10 soil borings and subsequent installation and completion of the borings into monitoring wells. The depths and locations of the piezometers and monitoring wells are described below.

The two piezometers were installed within the sand pack of the NoVOCs™ well: one adjacent to the NoVOCs™ recharge screen (PZ-01), and one adjacent to the NoVOCs™ intake screen (PZ-02). The natural groundwater flow direction across the site is generally to the west. Seven crossgradient monitoring wells were installed at four distances from the NoVOCs™ well, as follows: a cluster of three wells 30 feet from the NoVOCs™ well (monitoring wells MW-45, MW-46, and MW-47), a well pair 60 feet from the NoVOCs™ well (monitoring wells MW-48 and MW-49), and single monitoring wells 90 and 105 feet from the NoVOCs™ well (monitoring wells MW-50 and MW-51). Two downgradient monitoring wells (MW-52 and MW-53) were installed as a pair about 100 feet from the NoVOCs™ well, and a single monitoring well (MW-54) was also installed 100 feet upgradient of the NoVOCs™ well. Each monitoring well was screened at one of the following three intervals: at the top of the treatment zone (between about 41 and 47 feet bgs [-19.1 to -25.0 feet MLLW]), in the middle of the treatment zone (between about 49 and 62 feet bgs [-35.1 to -40.4 feet MLLW]), and at the bottom of the treatment zone (between about 67 and 78 feet bgs [-43.6 to -58.0 feet MLLW]). These screen intervals provided information on changes in contaminant concentrations through the aquifer. A summary of well screen intervals for the individual wells is presented in Table 1.

2.3.2 Evaluation Design

This section describes the sampling and analysis program and sample collection frequency and locations. The purpose of the demonstration design was to collect and analyze samples of known and acceptable quality to achieve the objectives stated in Section 2.2.

2.3.2.1 Sampling and Analysis Program

To meet the demonstration objectives, the sampling and analysis program was divided into three phases: (1) baseline sampling, (2) long-term sampling, and (3) dye trace sampling.

Baseline Sampling. Baseline sampling included the collection of groundwater samples from the monitoring wells to determine VOCs, SVOCs, dissolved metal concentrations, and select geochemical parameters at the start and end of the evaluation. Data obtained during the baseline sampling events were used to achieve secondary objectives S1 and S2. The first baseline sampling was conducted in April 1998 to assess contaminant concentrations in the aquifer before startup of the NoVOCs™ system under early operating conditions. A second baseline sampling event was conducted in September 1998 to assess contaminant concentrations in the aquifer before startup of the NoVOCs™ system under reconfigured operating conditions. An overview of the sampling and analysis conducted for baseline sampling is shown in Table 2.

TABLE 1

WELL SCREEN INTERVALS
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Well	Description	Distance From NoVOCs™ Well (feet)	Screen Interval Depths (feet bgs)	Designation
IW-01	NoVOCs™ well	0	43 to 47 and 72 to 78	System well
PZ-01	NoVOCs™ recharge piezometer	0	40 to 45	Shallow
PZ-02	NoVOCs™ intake piezometer	0	70 to 75	Deep
MW-45	Crossgradient monitoring well	30	42 to 47	Shallow
MW-46	Crossgradient monitoring well	30	57 to 62	Intermediate
MW-47	Crossgradient monitoring well	30	72 to 77	Deep
MW-48	Crossgradient monitoring well	60	52 to 57	Intermediate
MW-49	Crossgradient monitoring well	60	67 to 72	Deep
MW-50	Crossgradient monitoring well	90	52 to 57	Intermediate
MW-51	Crossgradient monitoring well	105	49 to 54	Intermediate
MW-52	Downgradient monitoring well	100	41 to 46	Shallow
MW-53	Downgradient monitoring well	100	72 to 77	Deep
MW-54	Upgradient monitoring well	100	38 to 78	Shallow

Note:

bgs Below ground surface

TABLE 2

SAMPLING AND ANALYSIS SUMMARY
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Sampling Event	Sampling Location	Sample Type	Analytical Parameter	Sampling Frequency	Where Analyzed	Method	Purpose
Baseline Sampling Event	PZ-01 and PZ-02 and MW-45 through MW-54	Groundwater	VOCs	Before and after demonstration of the NoVOCs™ technology	Laboratory	8260B (SW-846)	S2
			SVOCs		Laboratory	8270 (SW-846)	S2
			Dissolved metals		Laboratory	3010/6010B (SW-846)	S2
			Dissolved organic carbon		Laboratory	9060 SW-846	S2
			Alkalinity		Laboratory	310.1 (MCAWW)	S2
			Total dissolved solids		Laboratory	160.1 (MCAWW)	S2
			Dissolved oxygen		In field	360.1 (MCAWW)	S2
			Redox potential		In field	2580B (APHA)	S2
			pH		In field	150.1 (MCAWW)	S2
			Specific conductivity		In field	120.1 (MCAWW)	S2
			Temperature		In field	170.1 (MCAWW)	S2

TABLE 2 (Continued)

SAMPLING AND ANALYSIS SUMMARY
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Sampling Event	Sampling Location	Sample Type	Analytical Parameter	Sampling Frequency	Where Analyzed	Method	Purpose
Long-term Sampling	PZ-01 and PZ-02 and MW-45 through MW-54	Groundwater	VOCs	PZ-01 and PZ-02 once per week for the first month and monthly thereafter for 5 months. MW-45 through MW-54 monthly for 6 months	Laboratory	8260B (SW-486)	P1, S1
			Dissolved oxygen		In field	360.1 (MCAWW)	S2
			Redox potential		In field	2580B (APHA)	S2
			pH		In field	150.1 (MCAWW)	S2
			Specific conductivity		In field	120.1 (MCAWW)	S2
			Temperature		In field	170.1 (MCAWW)	S2
	A1 through A4	Air	VOCs	Once per week for the first month and monthly thereafter for 5 months	Laboratory	TO-14 (TOCAA)	P3, S4

Notes:

VOC	Volatile organic compound
SVOC	Semivolatile organic compound
P1	Primary Objective 1
S1	Secondary Objective 1
SW-846	Test Methods for Evaluating Solid Wastes (EPA 1994)
TOCAA	Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air (EPA 1984)
MCAWW	Methods for Chemical Analysis of Water and Wastes (EPA 1983)
APHA	American Public Health Association Standard Methods for the Examination of Water and Wastewater, 18th Edition, American Public Health Association, 1992

Long-term Sampling. Long-term sampling included the collection of groundwater samples for analysis of VOCs and select geochemical parameters and collection of air samples for analysis of VOCs. These samples were collected weekly for the first month of the demonstration and then monthly thereafter for 1 month. Data from these sampling events were used to evaluate the project objectives presented in Section 2.2. Each of these long-term sampling events is discussed below. Because of system operational difficulties during the evaluation, long-term sampling was limited to 6 weeks instead of the planned 6 month monitoring period. An overview of the sampling and analysis conducted for long-term sampling is shown in Table 2.

VOC Sampling. Groundwater samples were collected weekly during the first month of the demonstration from piezometers PZ-01 and PZ-02 and monthly thereafter for 1 month to evaluate the removal efficiency of the system. In addition, groundwater samples were collected from monitoring wells MW-45 through MW-54 during the first month of system operation to evaluate the change in contaminant concentrations within the treatment cell.

Select Geochemical Parameters Sampling. Dissolved oxygen, specific conductance, temperature, oxidation/reduction potentials, and pH were measured in the field in samples from piezometers PZ-01and PZ-02 and monitoring wells MW-45 through MW-54 during each groundwater sampling event. The results of these analyses were used to evaluate changes in aquifer chemistry caused by the NoVOCs™ system.

Air Sampling. VOC concentrations were measured by collecting air samples from the influent and effluent of both the NoVOCs™ and Thermatrix systems from air sampling ports A1 through A4 using Summa canisters and analyzing the samples using EPA Method TO-14. Air flow rates were also measured. Air samples were collected from the sampling ports weekly during the first month of the evaluation (four events) and monthly thereafter for 1 month (one event). These data were used to evaluate the contaminant mass removal of the NoVOCs™ system and the effectiveness of the Thermatrix flameless oxidation process. Air sampling was terminated because of operational problems with the NoVOCs™ system.

Dye Trace Sampling. Baseline groundwater and carbon pack samples were collected from monitoring wells MW-45 through MW-54 to assess the presence of potential tracer interferences and to evaluate fluorescent background levels. The baseline sampling events were conducted after the monitoring wells were installed and before system startup. The sampling events were conducted 1 week apart from one another. Samples collected during the baseline sampling events were analyzed to assess the presence of natural background fluorescence. Any background fluorescence identified was compared to the spectral characteristics of Fluorescein and Rhodamine WT to determine the potential degree of interference with dye detection. Because of intermittent operation of the NoVOCs™ system, the planned dye tracer study was not conducted. Therefore, no further dye trace sampling was conducted beyond the baseline sampling event.

2.3.2.2 Sampling and Measurement Locations

Groundwater samples were collected at 12 locations, and air samples were collected at four locations (see Figures 4 and 5). The analytical and field measurement parameters for each of these locations are provided in Table 2.

The four air monitoring locations are identified in Figure 4 as A1 through A4. Air samples were collected at sampling port A1, located immediately before air injection into the NoVOCs™ well, and sampling port A2, located immediately after air was extracted from the NoVOCs™ well. Air samples were also collected immediately before entering the Thermatrix flameless oxidations system at sampling port A3, and immediately after exiting the Thermatrix flameless oxidations system at sampling port A4. All air samples from system air sampling ports were monitored for VOCs. In addition, air flow rates were measured at sampling ports A1 and A2. Air sampling ports A2 and A3 are similar, except for their physical location in the treatment process and that air sampling port A3 is mixed with ambient air as necessary to maintain a consistent air flow rate into the Thermatrix system.

The two piezometers and 10 groundwater monitoring locations are identified on Figure 5 as piezometers PZ-01 and PZ-02 and monitoring wells MW-45 through MW-54. The two piezometers and five of the monitoring wells, as shown, are within the projected treatment cell and at the projected horizontal extent of the treatment cell. Five of the wells are just outside the projected treatment cell. Because well placement was based on the projected radius of the treatment cell of 90 feet, all wells were monitored during the demonstration.

2.3.3 Sampling Methods

This section describes the procedures for collecting representative groundwater and air samples and measuring air flow rate at each designated sampling location.

2.3.3.1 Groundwater Samples

Each monitoring well was equipped with a dedicated bladder pump that was used to collect groundwater samples. The bladder pumps were placed at the mid-screen interval in each monitoring well. A low-flow purge method was used to ensure that representative samples were collected. During purging, field parameters, including pH, temperature, and specific conductivity were measured at least once every 5 gallons. Once field parameters stabilized to within 10 percent of the previous measurement, samples were collected. Groundwater samples were collected by gently introducing water from the pump discharge line directly into prepreserved sample containers. Immediately after collection, groundwater samples were labeled and placed in a cooled ice chest for transport to the analytical laboratory. A similar procedure was used to collect groundwater samples from the two piezometers, except that a peristaltic pump with dedicated surgical tubing was used instead of dedicated bladder pumps.

2.3.3.2 Air Sampling

Duplicate, 1-hour integrated air samples were collected from each sampling location using Summa canisters equipped with flow meters. Each sampling event used new Teflon® tubing and stainless-steel connections. Duplicate samples were collected by installing union tees at each sample port and connecting the inlet tubes from the union tee to separate Summa canisters. A minimal length of Teflon® tubing was used for all connections. Once all connections were made and the Summa canisters were ready for sampling, the vacuum pressure in each Summa canister was measured using a pressure gauge and the reading recorded on the sample label. The Summa canister valve was then opened, and the canister was allowed to fill for a period of 1 hour. After the 1-hour period, the valve was closed, and the vacuum pressure was remeasured and recorded on the sample label. Immediately after collection, air samples were labeled and placed in a Summa canister shipping container for transport to the analytical laboratory.

For the collection of air samples from sample port A4, air samples were withdrawn from the stack gas through a condensate trap because of the very high moisture content. The trap was placed in an ice bath to condense and remove considerable liquids from the air stream during collection of the duplicate, 1-hour integrated air samples.

2.3.3.3 Air Flow Measurements

The volumetric flow rate at the influent and effluent air stream sampling ports (A1 and A2) was measured using in-line, orifice plates. The orifice plates used to determine air flow were 2-inch-diameter (influent line) and 3-inch-diameter (effluent line) orifice plates manufactured by Lamda Square, Inc. By measuring the drop in pressure across the orifice plate, the volumetric air flow rate was determined by plotting the pressure on certified flow curves. The pressure drop across the orifice plates was measured using a magnehelic gauge. The flow curves were certified by the manufacturer.

2.3.4 Analytical Methods

Groundwater and air samples were analyzed for the parameters outlined in the TEP/QAPP (Tetra Tech 1998) using the methods specified in Table 3. For the SITE evaluation, VOCs and air flow rate were considered to be critical parameters. VOC concentrations were determined using the gas chromatography/mass spectrometry Method 8260B capillary column technique. Because both matrices (groundwater and offgas) produced a vapor phase that was desorbed from a trap onto a gas chromatographic column, the analysis is the same. Compounds in the samples were detected and identified using the mass spectra produced as compared to the mass spectra from the initial calibration for each compound. The concentration of each compound was determined by comparison of the sample response to the daily continuing calibration response. Air flow rate was determined as described in Section 2.3.3.3. Noncritical parameters for the SITE evaluation were measured using the methods and procedures presented in Table 3.

2.3.5 Quality Assurance and Quality Control Program

QC checks and procedures were an integral part of the NoVOCs™ SITE evaluation to ensure that QA objectives were met. These checks and procedures focused on collection of representative samples

TABLE 3

ANALYTICAL METHODS
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Analysis	Matrix	Method	Reference
Volatile Organic Compounds	Groundwater	8260B	SW-846
	Air	TO-14/8260B	TOCAA/SW-846
Flow rate	Air	Oriface plate	Certified flow curves
Dissolved Metals	Groundwater	3010/6010B	SW-846
Total Dissolved Solids	Groundwater	160.1	MCAWW
Total Organic Carbon	Groundwater	9060	SW-846
Alkalinity	Groundwater	310.1	MCAWW
Dissolved Oxygen	Groundwater	360.1	MCAWW
Redox Potential	Groundwater	2580B	APHA
Specific Conductivity	Groundwater	120.1	MCAWW
Temperature	Groundwater	170.1	MCAWW
pH	Groundwater	150.1	MCAWW

Notes:

SW-846	Test Methods for Evaluating Solid Wastes (EPA 1994)
TOCAA	Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air (EPA 1984)
EPA	Methods for Chemical Analysis of Water and Wastes (EPA 1988)
APHA	American Public Health Association Standard Methods for the Examination of Water and Wastewater, 18th Edition, American Public Health Association, 1992
MCAWW	Methods for Chemical Analysis of Water and Wastes (EPA 1983)

without external contamination and on generation of comparable data. Two types of QC checks and procedures were conducted during the demonstration: (1) checks controlling field activities, such as sample collection and shipping; and (2) checks controlling laboratory activities, such as extraction and analysis. The results of the field QC checks are summarized in Volume VI, Appendix F.

2.3.5.1 Field Quality Control Checks

As a check on the quality of field activities, including sample collection, shipment, and handling, three types of field QC checks (field blanks, trip blanks, and equipment blanks) were collected. In general, these QC checks assessed potential field contamination of the samples and helped ensure that the degree to which the analytical data represent actual site conditions. Any QC results that failed acceptance criteria were reported to the project manager or QA manager as soon as possible, and corrective action was taken. If a field QC check sample exceeded the established criteria for any analytical parameter, analytical results for that parameter in all associated samples having the analyte concentration above the quantitation limit were flagged during post-laboratory validation.

2.3.5.2 Laboratory Quality Control Checks

Laboratory QC checks were designed to determine precision and accuracy of the analyses, to demonstrate the absence of interferences and contamination from glassware and reagents, and to ensure the comparability of data. Laboratory-based QC checks consisted of method blanks, matrix spikes/matrix spike duplicates, sample duplicates, surrogate spikes, blank spikes/blank spike duplicates, and other checks specified in the analytical methods. The laboratory also performed initial calibrations and continuing calibration checks according to the specified analytical methods. The results of the laboratory internal QC checks for critical parameters are summarized on a method-specific basis in Volumes II through V, Appendix D.

Routine QC was performed for the noncritical general chemistry parameters. At least one laboratory duplicate and check standard was run for every batch (minimum of one per 20 samples) for alkalinity and total dissolved solids. Laboratory blanks were also run for these parameters. Duplicate samples were run for all other noncritical analyses at a frequency of 10 percent or at least one per batch. The relative percentage difference (RPD) acceptance criteria for duplicate analyses was 20 percent. Additionally, check standards and laboratory blank samples were run for metals analyses. The results of the laboratory internal QC checks for noncritical analyses are presented in Volumes II through V, Appendix D.

2.4 MODIFICATIONS TO THE TEST EVALUATION PLAN

Several modifications from the TEP/QAPP (Tetra Tech 1998) were made during the demonstration. To achieve the evaluation objectives, long-term sampling consisting of monthly sampling of groundwater and air for VOCs and weekly sampling of groundwater for fluorescent tracer dyes for six consecutive months was planned. However, long-term sampling was limited to the first month of the demonstration because of sporadic operation of the NoVOCs™ system at Site 9. In addition, the dye trace study was not conducted; no fluorescent dyes were injected into the aquifer. Because the dye tracer study was not conducted, primary objective P2 (determine the radius of the NoVOCs™ treatment cell) could not be evaluated. Instead, indirect methods consisting of a series of aquifer pump tests were used to indirectly evaluate the objective. Aquifer testing also provided additional information on the hydrogeologic characteristics of the site. A detailed description of the methods and procedures used to conduct the aquifer testing is presented in the Hydrogeological Investigation of the Aquifer Treated by the NoVOCs™ System (Tetra Tech 2000), which is provided as Volume I, Appendix C.

Several modifications to the sampling methods and procedures outlined in the TEP/QAPP were also made during the demonstration. During baseline sampling on April 17, 1998, monitoring wells MW-53 and MW-54 were not sampled because of a malfunctioning bladder pump in monitoring well MW-53 and the presence of the multi-level diffusion sampler in monitoring well MW-54. Oxidation/reduction potential readings were not collected during the baseline sampling event, first weekly event, second weekly event, third weekly event, and first monthly sampling events because of field sampling error. In addition, during the fourth weekly sampling event, piezometers PZ-01 and PZ-02 could not be sampled because of the presence of pH probes in the piezometers. Therefore, only air samples were collected during the fourth weekly sampling event. During the first weekly sampling event, air pressure, temperature, and flow rate from air sampling ports A1 and A2 were obtained from MACTEC flow meter readings at the wellhead and NoVOCs™ control trailer; flow readings using the orifice plate were not collected.

These deviations and modifications to the TEP/QAPP do not appear to have significantly affected the overall usability of the data collected. In addition, where appropriate, data have been flagged to qualify their usability. Although a full evaluation of the system was not possible because of the operational problems encountered during the demonstration, the limited data that were collected provide an indication of system performance during the first month of operation.

3.0 EVALUATION RESULTS

This section presents the operating conditions as well as the measurement results and associated data quality for the SITE evaluation of the NoVOCs™ technology. The evaluation results have been supplemented by information collected during the demonstration by Bechtel, Gilbert Hill Associates, Umtanum, and MACTEC.

3.1 OPERATING CONDITIONS

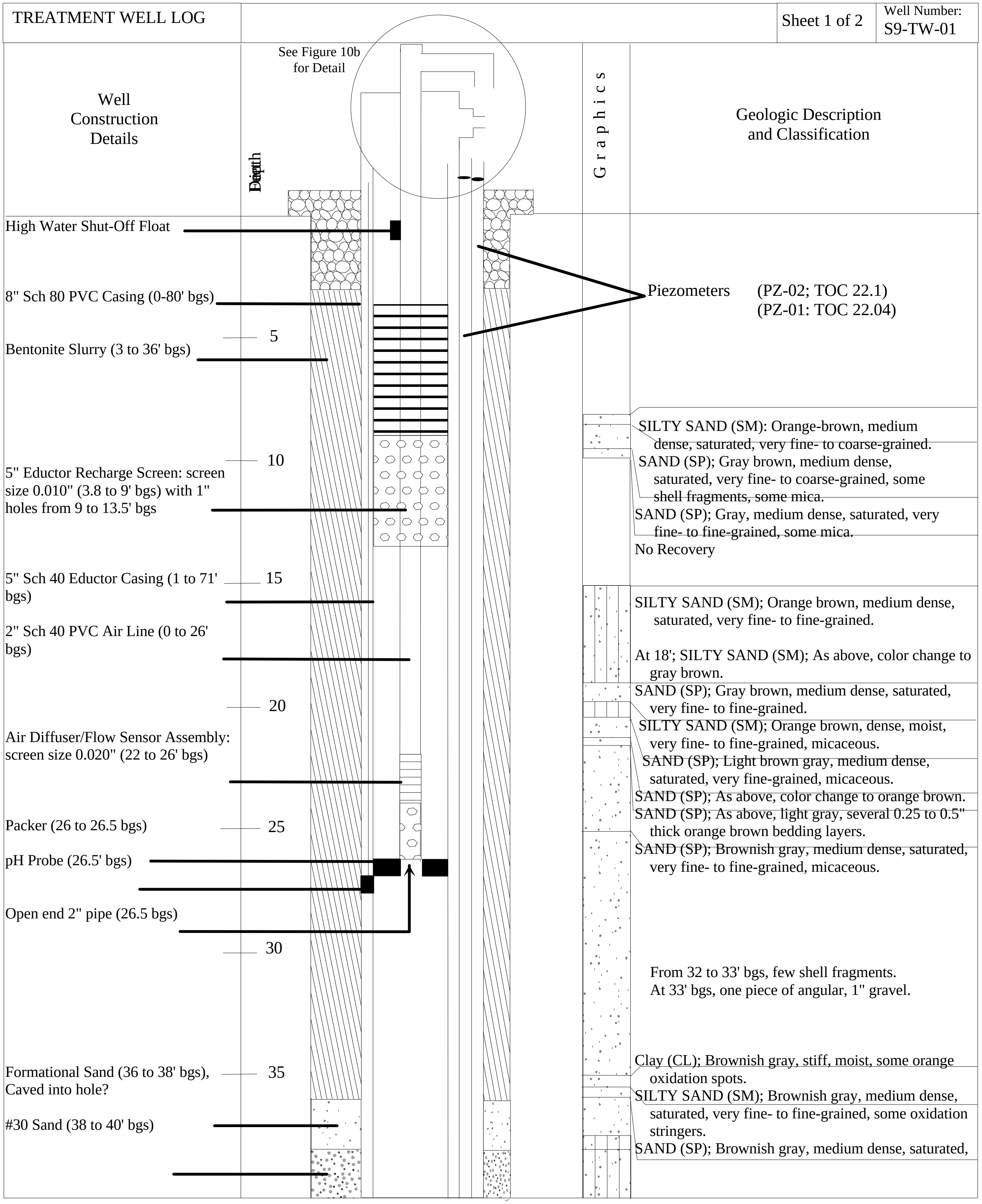
This section summarizes the configuration of the NoVOCs™ system, operating parameters, and system maintenance performed during the demonstration at Site 9. During the SITE demonstration, the NoVOCs™ system was operated at conditions determined by the vendor and SWDIV. To document the NoVOCs™ system operating conditions, groundwater influent and effluent and system process air stream were periodically monitored and sampled. The NoVOCs™ system was designed to operate continuously, 24 hours a day, 7 days a week; however during the demonstration, the system experienced significant operational difficulties.

3.1.1 NoVOCs™ and Thermatrix System Configurations

This section provides a description of the NoVOCs™ and Thermatrix system configurations.

3.1.1.1 NoVOCs™ System Configuration

The NoVOCs™ system installed at Site 9 consisted of an 8-inch-diameter, Schedule-80 polyvinyl chloride (PVC) casing with two screens; a 5-inch-diameter, Schedule 40 PVC eductor pipe to draw water from the contaminated zone; a 2-inch-diameter, Schedule 40 PVC airline with attached flow meter; a wellhead fixture with deflector plate; and associated seals and instrumentation components. The lithologic log generated during continuous coring of the NoVOCs™ borehole was used to locate the appropriate screen intervals. The A clay/silt layer was thought to be a possible hydraulic barrier; therefore, the NoVOCs™ well design was changed to accommodate a recharge zone located beneath the A clay/silt layer, and the extraction screen was installed above a cemented sandstone layer encountered at 78 feet bgs. An as-built diagram of the NoVOCs™ well is presented in Figures 10a through 10c.



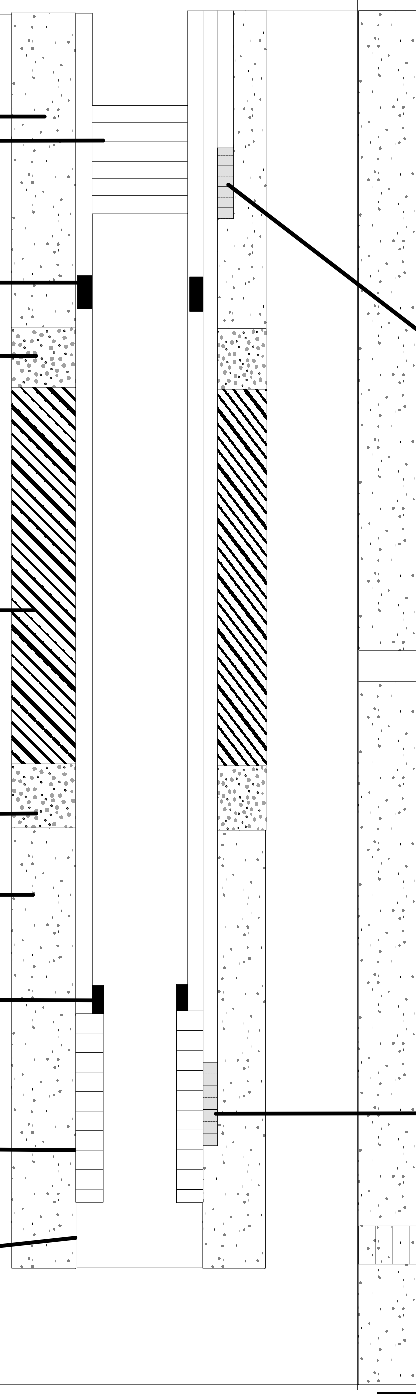
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 10a
NoVOCs™ AS-BUILT DIAGRAM

Tetra Tech EM Inc.

TREATMENT WELL LOG		Sheet 2 of 2	Well Number: S9-TW-01

Well Construction Details	Depth	Graphics	Geologic Description and Classification



#2/12 Sand (40 to 50' bgs)
Upper Recharge Screen: screen size (0.010" (43 to 47' bgs)

45

Packer (48' bgs)

50

#30 Sand (50-52' bgs)

55

Grout: Portland cement/bentonite (52 to 64' bgs)

60

#30 Sand (64 to 66 bgs)

65

#2/12 Sand (66 to 80' bgs)

4" PVC stub with rubber packer for 5" eductor pipe to slip onto

70

Pre-pack Slotted Screen (72 to 78' bgs): screen size 0.010", pre-pack diameter from 4 to 8 " with #2/12 sand inner 4" open pipe.

75

Sump (78 to 80' bgs)

80

very fine- to fine-grained, micaceous.
From 36.74 to 37' bgs, some shells with horizontal orientation.

SILTY SAND (SM); Brown, medium dense, saturated, very fine- to fine-grained, some mica.

SAND (SP); Brownish gray, medium dense, saturated, very fine- to course-grained, some mica and shell fragments.

SAND (SP); Gray, medium dense, saturated, very fine- to fine-grained, some mica, fine black grains.

PZ-01 recharge piezometer screen; screen size 0.010" (44 to 46' bgs)

SAND (SP); Gray, medium dense, saturated, very fine- to fine-grained, some mica, fine black grains.

From 58.5 to 60.25' bgs, SAND (SP); As above, 20% shell fragments with some horizontal bedding.
At 60' bgs, Difficult drilling, dense sand.
No Recovery
SAND (SP); Light gray, medium dense, saturated, very fine- to fine-grined, same mica and black grains.
SAND (SP); As above, with shell fragments.

Very dense sand to 66' bgs.

From 66.25 to 66.75' bgs, dense sand.
At 66.75' bgs, SAND (SP); As above, medium dense.

PZ-02 intake piezometer screen: screen size 0.010" (74 to 76' bgs).

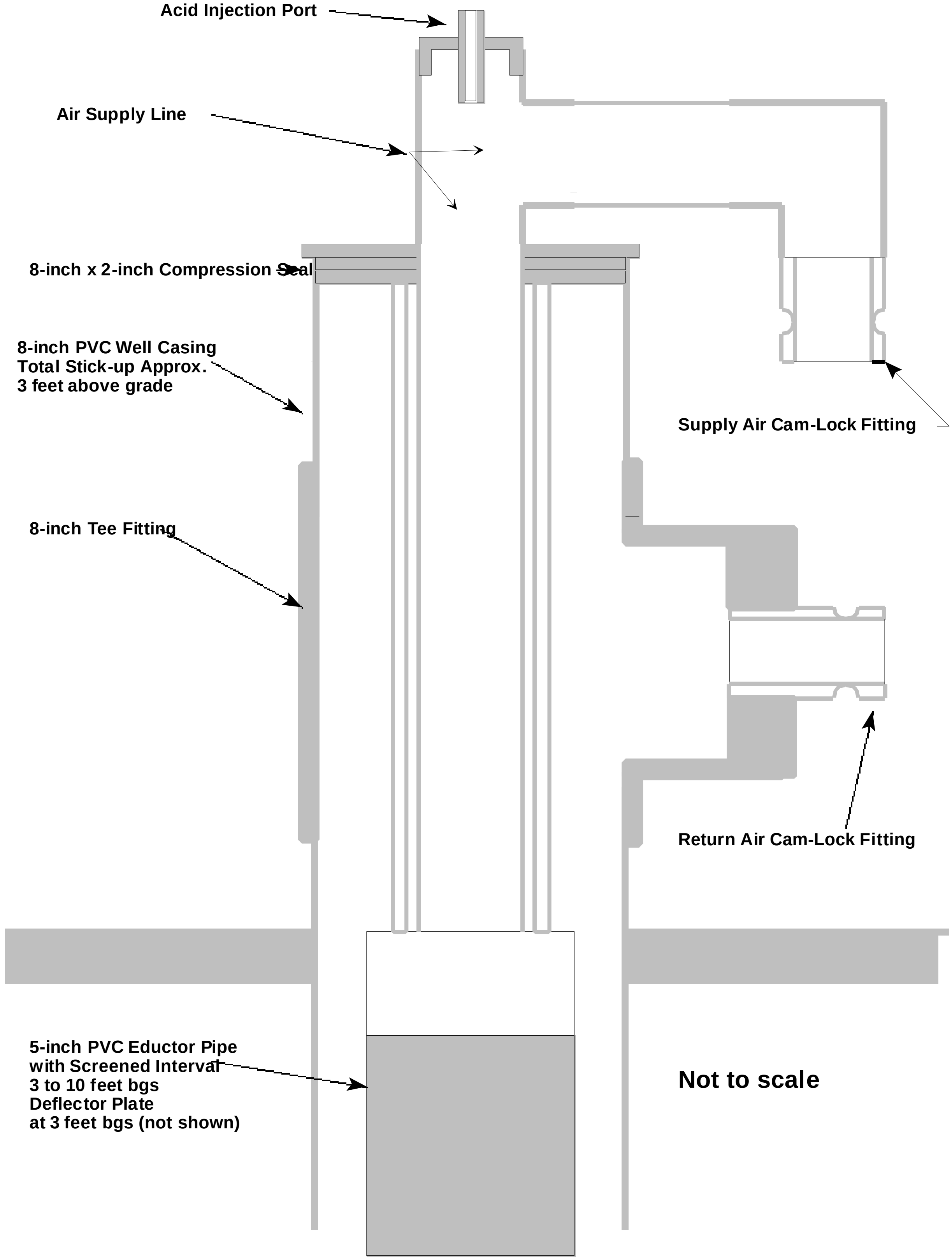
From 76 to 79' bgs, SAND (SP); As above, brownish gray.

From 78 to 79' bgs, SAND (SP); As above, gray, few shell fragments.
SILTY SAND (SM); Olive gray, dense, saturated, very fine- to coarse-grained.
Some pieces of cemented sandstone.

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 10a (continued)
NoVOCs™ AS-BUILT DIAGRAM

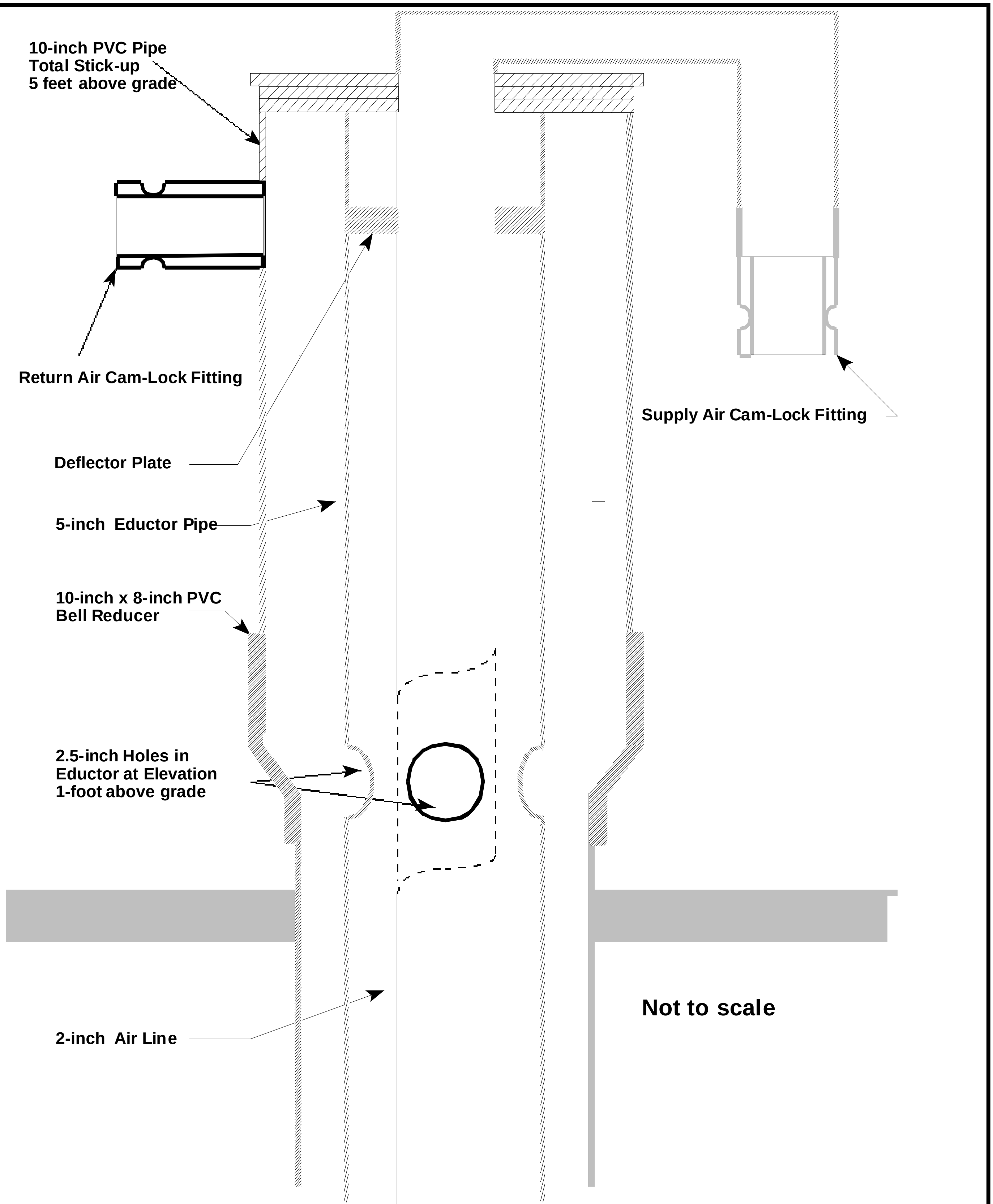
Tetra Tech EM Inc.



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 10b
WELL HEAD AS-BUILT DIAGRAM

Tetra Tech EM Inc.



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 10c
RECONFIGURED WELL HEAD
AS-BUILT DIAGRAM

Tetra Tech EM Inc.

The lower screen interval consisted of a prepack filter pack consisting of # 2/12 sand, an outside casing consisting of an 8-inch-diameter, Schedule 80 PVC, 10-slot screen (0.01 inch slots cut in the casing), and an inside casing consisting of a 4-inch-diameter, Schedule 40 PVC, 10-slot screen. The 4-inch-diameter inside casing extended above the prepack to provide a “stub” for the 5-inch-diameter eductor pipe to fit over, centralizing the bottom of the eductor pipe. The bottom of the lower interval screen was located at the top of the cemented sand layer at about 78 feet bgs, and extended from 72 to 78 feet bgs. The upper screen was 5 feet long and was located with its top below the silty sand layer at about 38 feet bgs, and extended from 43 to 47 feet bgs. The upper screen also consisted an 8-inch diameter, Schedule 80 PVC, 10-slot screen and a prepack filter pack of # 2/12 sand.

A 2-inch-diameter airline was used to inject air into the eductor pipe at a depth of about 10 feet below the static water table or about 27 feet bgs. The injection of air through the airline caused airlift pumping to occur within the well, drawing groundwater from the lower screen through the prepack filter, up the 4-inch PVC pipe, into the bottom of the 5-inch eductor, and up to the deflector plate located about 3 feet bgs. The deflector plate forced the water and air to pass through a series of 1-inch holes drilled near the top of the eductor pipe, causing separation of the water and air. The water was then allowed to fall into the annulus between the eductor pipe and the well casing and return to the aquifer through the upper well screen.

To measure the amount of groundwater being pumped by the NoVOCs™ system, a 1.5-inch orifice plate flow sensor was installed at the end of the air supply line. A pH electrode was also installed within the well annulus to measure pH levels in the upper recharge screen interval.

The aboveground components of the NoVOCs™ system consisted of a control trailer and an offgas treatment system. For the NoVOCs™ demonstration at Site 9, the Thermatrix flameless oxidation system was selected by SWDIV for treatment of the NoVOCs™ system offgas.

The major components of the NoVOCs™ control trailer consisted of the air injection blower, electrical control panel, and a Remote Telemetry Unit (RTU) programmable logic controller. The trailer also housed: (1) an inlet moisture separator; (2) a pump system to empty the moisture separator when the level reaches a high level; (3) an inlet filter; (4) an inlet air intake valve; (5) an inlet vacuum relief valve; (6) inlet and discharge pressure sensors; (7) an outlet temperature sensor; (8) an outlet high-pressure relief valve; and (9) air supply flow sensors (Clean Sites 1998).

The RTU provided local and remote (by telephone line) control of the blower. The blower could be started and stopped remotely, but none of the valves could be controlled remotely. The RTU was designed to shut down the NoVOCs™ system if: (1) blower discharge pressure was too high, (2) blower suction pressure was too low, (3) blower discharge temperature was too high, (4) the hydrochloric acid (HCl) drum level was too low, (5) the pH in the NoVOCs™ well was outside of operating range, (6) water levels in the NoVOCs™ well were too high, and (7) the Thermatrix treatment system was off line. The RTU also provided an indication of the cause of the shutdown. The off-normal pH shutdown feature was not provided in the original design, but was added in April 1998.

To address the operational problems experience by the NoVOCs™ system, the configuration of the NoVOCs™ system was modified by MACTEC from August 25 through September 4, 1998. Using the aquifer pump test data collected earlier in the demonstration, MACTEC modified the configuration of the air diffuser assembly, deflector plate assembly, and the wellhead. The diameter of the wellhead was increased from 8 to 12 inches. The well was extended to a height of about 5 feet above ground surface. In addition, the deflector plate assembly was moved from below grade to about 3 feet above ground surface. The hole size in the eductor pipe air was also increased from 1 to 2.5-inches in diameter to allow more water to pass through the eductor pipe from the deflector plate. This modification was made to increase the amount of head in the NoVOCs™ well recharge water column. By increasing head more water could be injected into the aquifer. The hole size in the eductor pipe was also increased to 2.5-inches in diameter because only four holes were drilled to allow the air and water stream to exit the eductor pipe.

The NoVOCs™ wellhead was located in an area at SITE 9 that had received sand dredged from San Diego Bay, making it about 12 feet higher in elevation than the area immediately to the north. Support equipment, including the NoVOCs™ system control trailer and Thermatrix offgas treatment system was located about 300 feet northeast from the wellhead. The support equipment serviced the wellhead using one 2-inch PVC line for air supply, one 3-inch PVC line for air return, and various electrical and chemical services supplied through 0.75- and 1-inch PVC conduits. All services went under a road between the support equipment and the wellhead, and up the hill created by the fill from the bay. Figure 11a is a photograph of the wellhead looking toward downtown San Diego to the east. Figure 11b is a close up photograph of the NoVOCs™ wellhead. Figure 11c is a photograph of the service equipment taken from the elevated area and looking to the northeast. The trailer in Figure 11c contains a blower and moisture separator to supply air to the NoVOCs™ well and to process the return air. The skid-mounted equipment immediately behind the trailer is the Thermatrix offgas treatment system. The equipment behind the

Thermatrix skid and the areas of land covered by plastic are components of a soil vapor extraction system unrelated to the NoVOCs™ demonstration. The photographs in Figure 11a through 11c were taken in mid-May after modifying the NoVOCs™ system to include a pH shutdown system (see Section 3.1.3). Figure 11d shows the air line connections leaving the trailer in late February 1998 after the initial system installation.

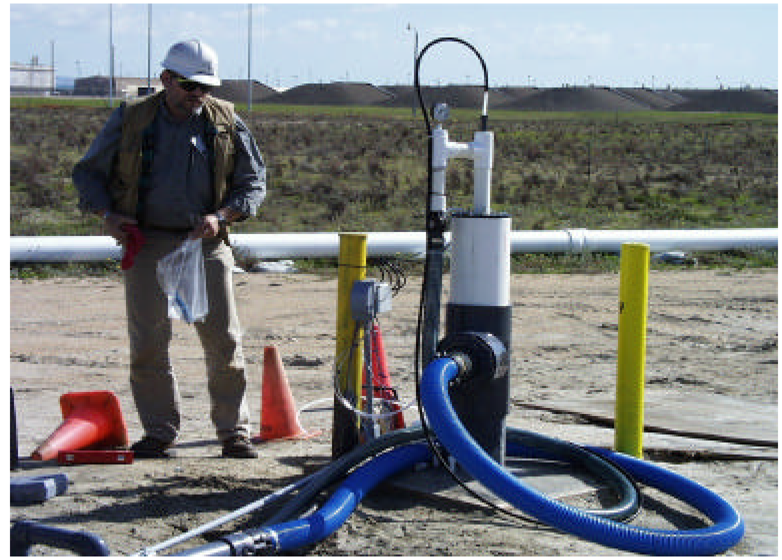
3.1.1.2 Thermatrix Flameless Thermal Oxidation System Configuration

The offgas from the NoVOCs™ well was treated by the Thermatrix flameless oxidation system. The Thermatrix system is a patented process designed for treatment of air streams containing chlorinated VOCs. The Thermatrix system differs from conventional incineration and oxidation systems in that the oxidation of organics occurs in a bed of chemically inert ceramic materials without the presence of a flame.

The Thermatrix system used during the demonstration was a skid-mounted system that was located near the NoVOCs™ trailer. The VOC-laden offgas from the NoVOCs™ system was piped from the NoVOCs™ wellhead through the NoVOCs™ trailer to a knock-out pot to remove excess moisture prior to treatment by the Thermatrix oxidizer. A schematic diagram of the Thermatrix system is presented as Figure 12. The Thermatrix system was designed to treat up to 2,500 parts per million on a volume per volume basis (ppm v/v) of VOCs in air at a flow rate of 250 standard cubic feet per minute (scfm). The ratio of air and fuel added to the offgas mixture was controlled by internal sensors that regulated the gas flow rates and maintained the optimal treatment temperature. Propane was used as a supplementary fuel source by the Thermatrix system.

The oxidizer consists of a metal containment vessel with internal refractory linings and a ceramic matrix bed. As the gases pass through the ceramic matrix bed towards the reaction zone, they absorb heat, and

Photograph 11a: Service Equipment



Photograph 11b: Wellhead

Photograph 11c: Control Trailor

Photograph 11d: Wellhead Area

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 11
NoVOCs™ WELL PHOTOGRAPHS

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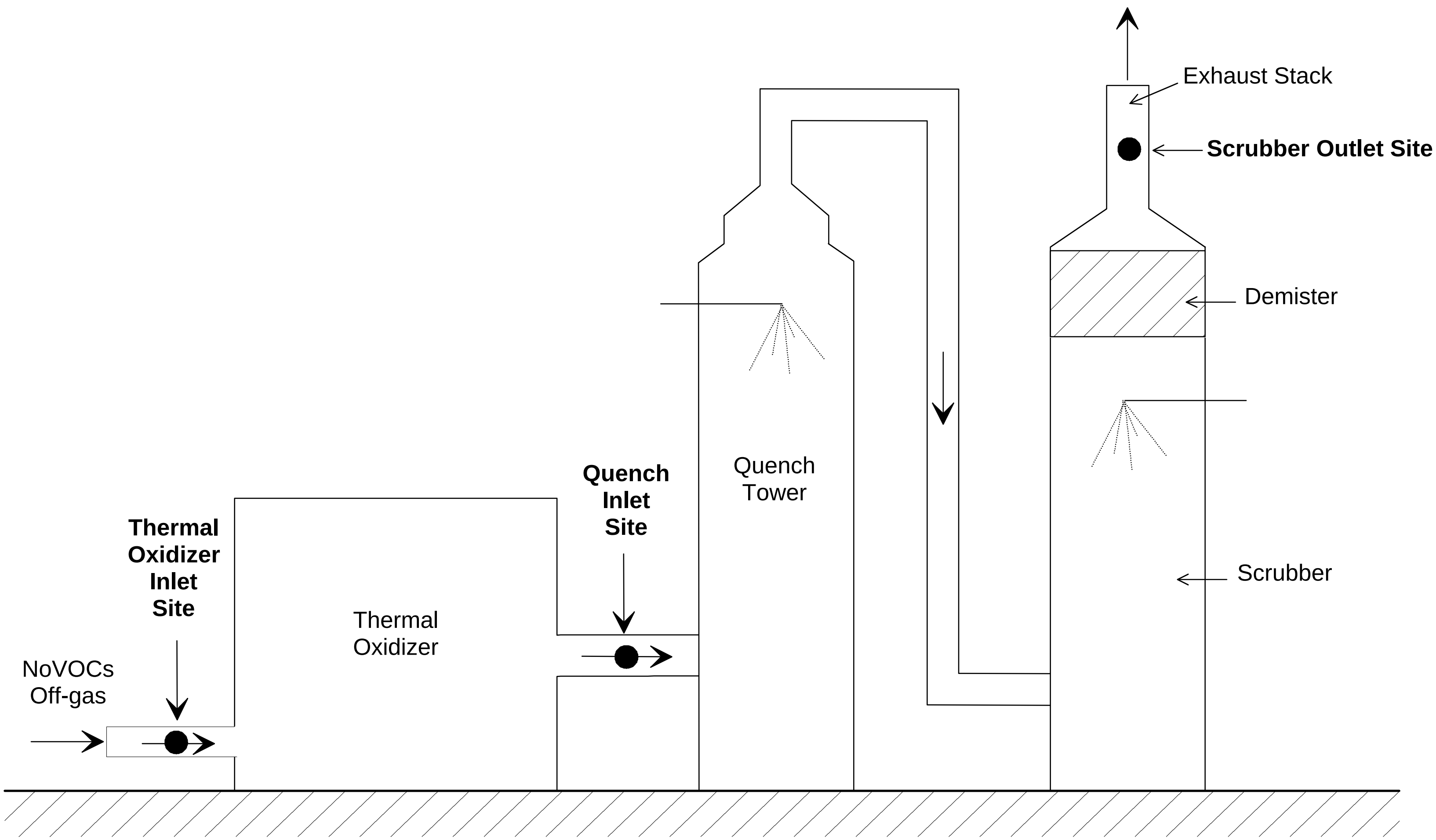

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 12
THERMATRIX FLAMELESS OXIDATION SYSTEM

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by the time they reach the reaction zone, the temperature reaches approximately 1,800 EF. At this temperature, thermal destruction and oxidation will occur, and the organic compounds in the air stream are converted to carbon dioxide (CO_2), water vapor, and HCl. The oxidation process is exothermic, and the released heat is reabsorbed by the ceramic matrix.

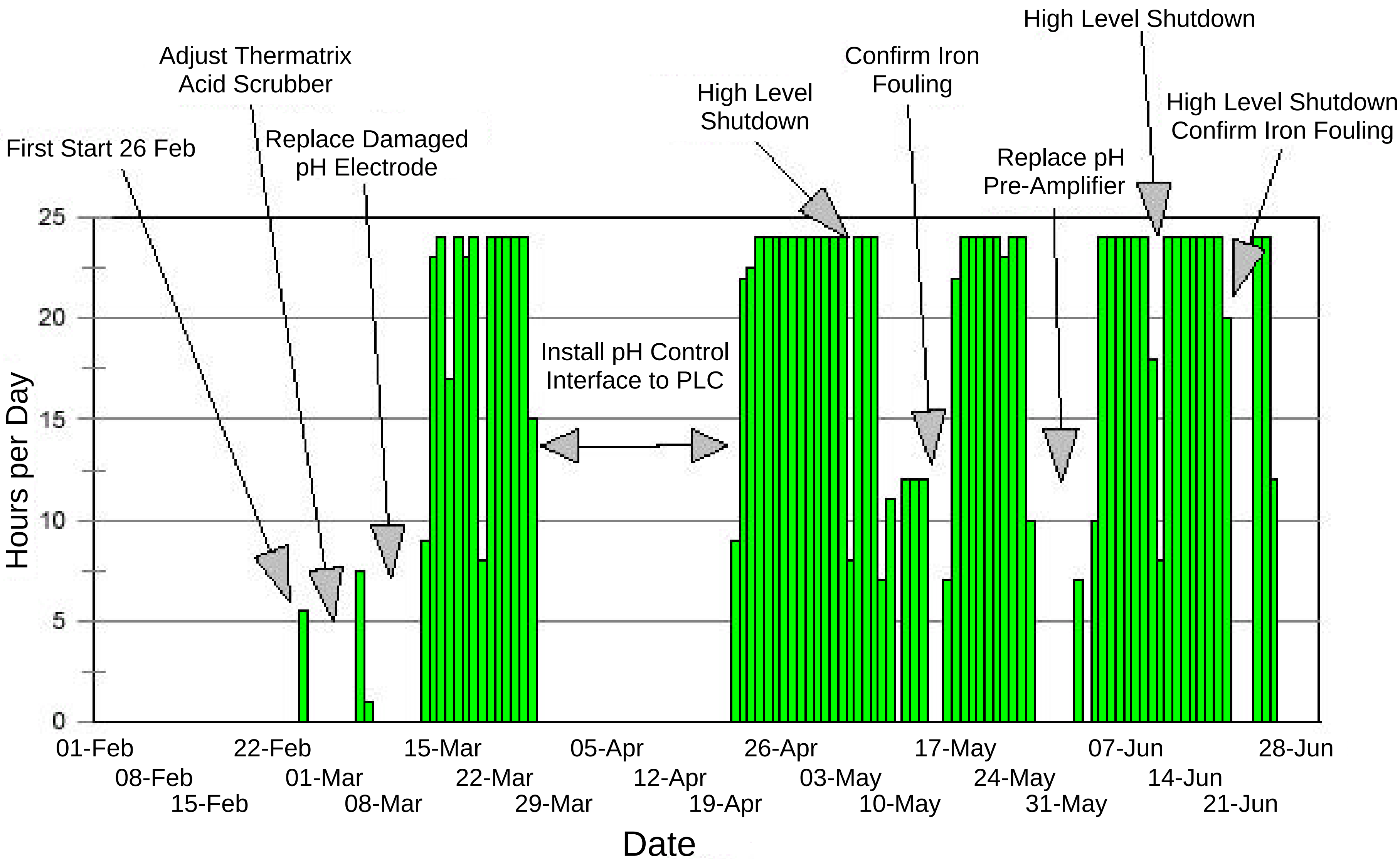
The processed gas stream exits the oxidizer through the bottom side of the unit. The flue gas leaving the oxidizer was expected to contain an average of about 4 lb/hr of HCl. A quench and scrubber system was incorporated into the Thermatrix design to remove 99 percent of the HCl before exhausting to the atmosphere. Blowdown water from this system was neutralized before being discharged to the sanitary sewer onsite.

3.1.2 NoVOCs™ Demonstration Operational Data Narrative

The NoVOCs™ system was monitored by Bechtel on a regular basis to evaluate its performance. System operating parameters monitored by Bechtel included blower suction, blower temperature, air flow rate, wellhead pressure, pumping rate, and pH in the groundwater discharged from the system. These parameters were documented in the field and recorded by the RTU. A summary of the operating parameter results measured during the demonstration is presented in Section 3.2.2.3. In addition, a system operation summary, documenting system operating time on a daily basis is graphically depicted in Figures 13a through 13c).

NoVOCs™ system operating conditions varied throughout the evaluation and can be generalized into four main operating periods: System Startup and Shakedown (February 26 through March 26, 1998), Early System Operation (April 20 through June 19, 1998), Reconfiguration Operation (September 24 through October 30, 1998), and Final Configuration Operation (December 4, 1998 through January 4, 1999).

The operating periods during the NoVOCs™ demonstration were conducted under varying configurations of the well internal components and various settings of operating parameters, such as supply air flow, pressure, and pH. Operations conducted in the later operating periods of the demonstration also included the addition of a biocide to control biological fouling of the well and two different chemical treatments to control iron fouling. The operating periods are shown graphically in Figure 13a through 13c. Selected

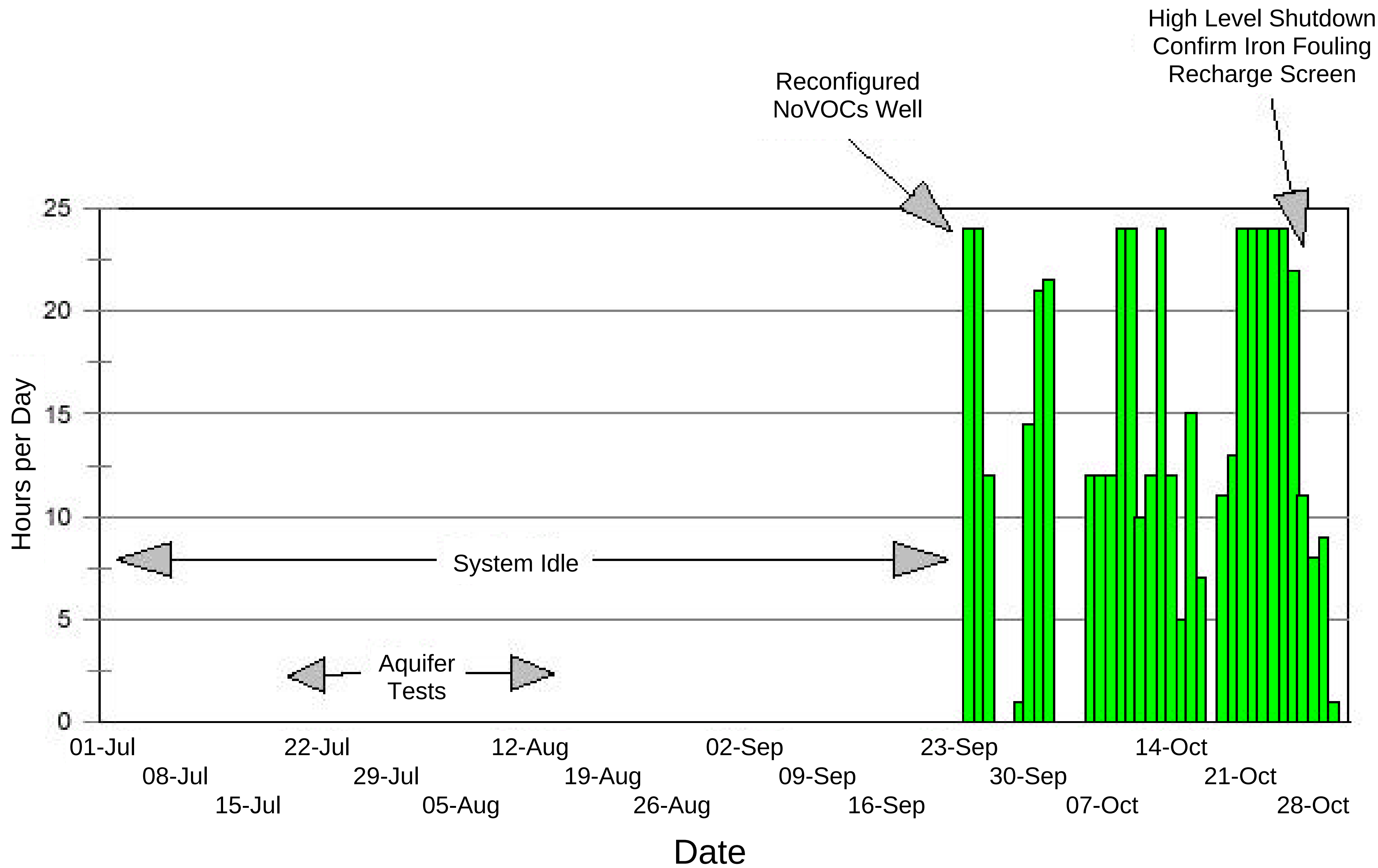


Source: Modified from Bechtel (1998)

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

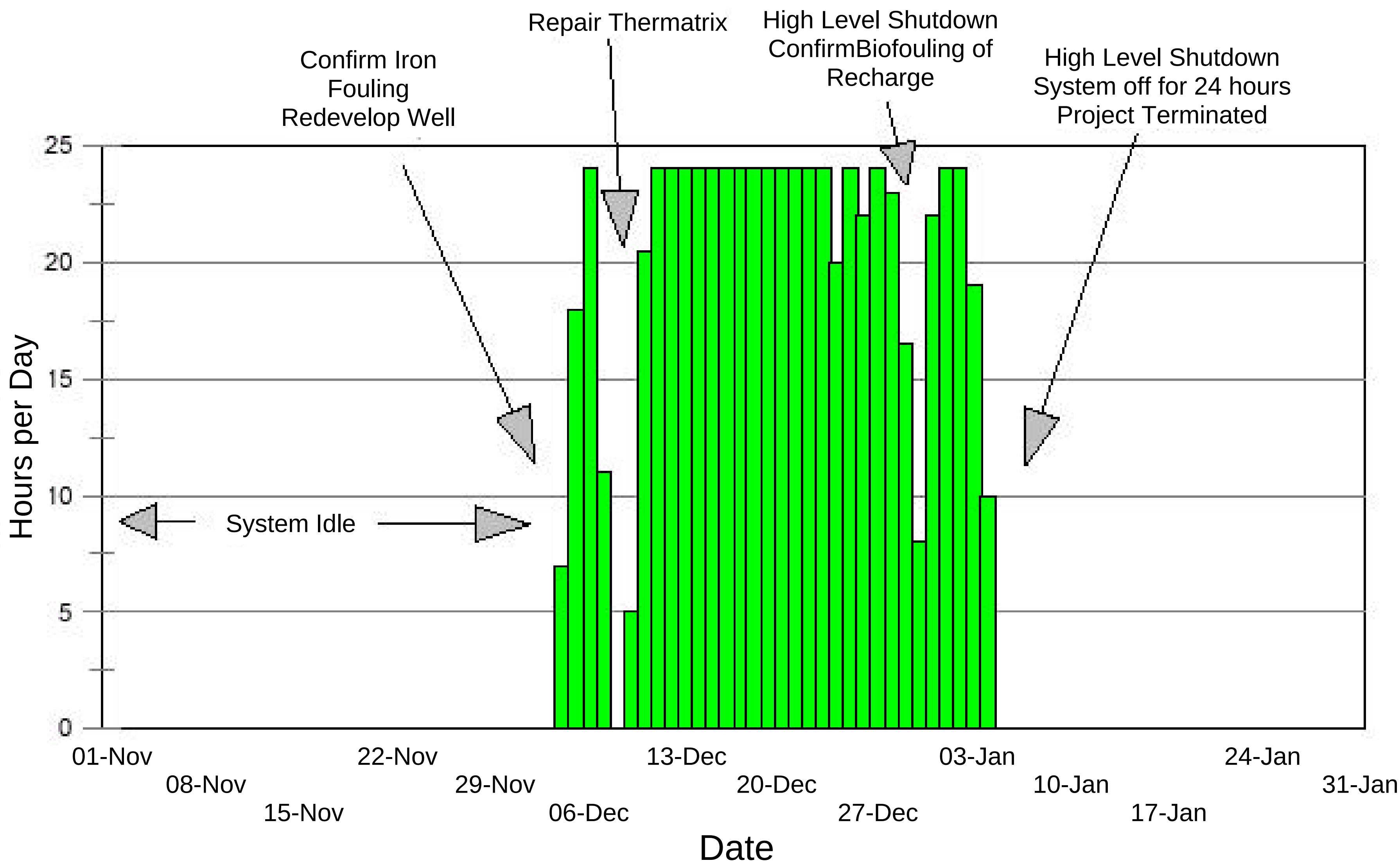
FIGURE 13a
NoVOCs™ SYSTEM BLOWER RUN TIME
Sheet 1

Tetra Tech EM Inc.



Source: Modified from Bechtel (1998)

NoVOCs™ SITE Demonstration Site 9, NAS North Island, California
FIGURE 13b **NoVOCs™ SYSTEM BLOWER RUN TIME** **Sheet 2**
Tetra Tech EM Inc.



Source: Modified from Bechtel (1998)

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 13c
NoVOCs™ SYSTEM BLOWER RUN TIME
Sheet 3

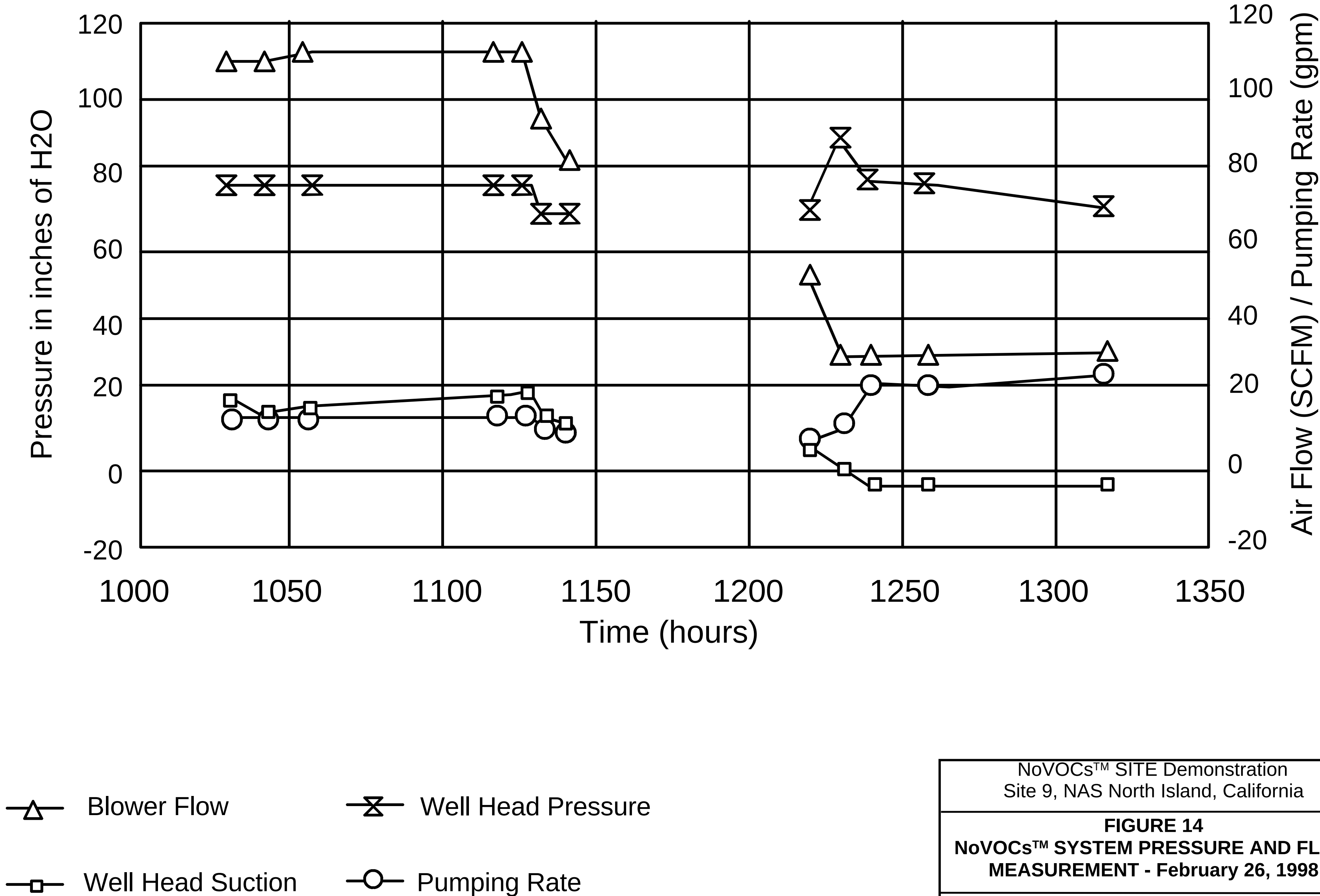
Tetra Tech EM Inc.

pertinent operational parameters and mechanical configuration modifications affecting these periods are discussed in the following sections. Additional discussion of fouling as it applies to the NoVOCs™ installation at NAS North Island is presented in Section 3.1.3.

3.1.2.1 System Startup and Shakedown — February 26 through March 26, 1998

The NoVOCs™ system was installed in January and February 1998 and began operation on February 26, 1998, along with the Thermatrix offgas treatment system. Because the Thermatrix unit was unable to maintain effluent pH in an operable range, the NoVOCs™ system was only operated for about 6 hours on February 26, 1998. The brief startup operation was useful in determining the need to modify the preliminary configuration of the NoVOCs™ system. The preliminary design called for supply air flow of about 115 scfm. At this air flow, the wellhead was under constant positive pressure. The airlift pumping action of the NoVOCs™ system is very sensitive to back pressure. This means that a positive pressure in the wellhead will tend to reduce the pumping rate of the well. This situation was observed during the initial startup and is shown in Figure 14. Figure 14 indicates the values observed for blower flow in scfm, blower pressure measured in the air supply line at the wellhead (in inches of water), wellhead suction measured in the well casing at the wellhead (also in inches of water), and the indicated water pumping rate (in gallons per minute). In addition to the back pressure effect, at higher air flow rates, the water pumping rate will decrease with increasing air flow as the air-water flow regime changes from churn flow to annular flow. In the annular flow regime, the air stream occupies most of the volume of the pipe with water flow limited to a thin layer on the pipe walls.

The system began operation with a positive pressure of about 20 inches of water inside of the casing on the return air side of the system. This configuration produced an indicated pumping rate of about 15 gpm, which decreased to about 10 gpm as the supply air flow was reduced. The air flow was further reduced until the system registered a negative pressure at the return side of the wellhead, at which point the indicated pumping rate increased to over 20 gpm. The system was operated briefly on March 4 and 5, 1998; however, it was discovered that the submerged pH electrode inside of the NoVOCs™ well had shorted out and needed to be replaced. Replacement parts were procured and the system was started for shakedown operation on March 13, 1998. The system operated continuously until March 26, 1998, with only relatively brief shutdowns for inspection, flow balancing, and minor adjustments. During the shakedown period, the system was observed to operate normally with an average indicated pumping rate



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 14
NoVOCs™ SYSTEM PRESSURE AND FLOW MEASUREMENT - February 26, 1998

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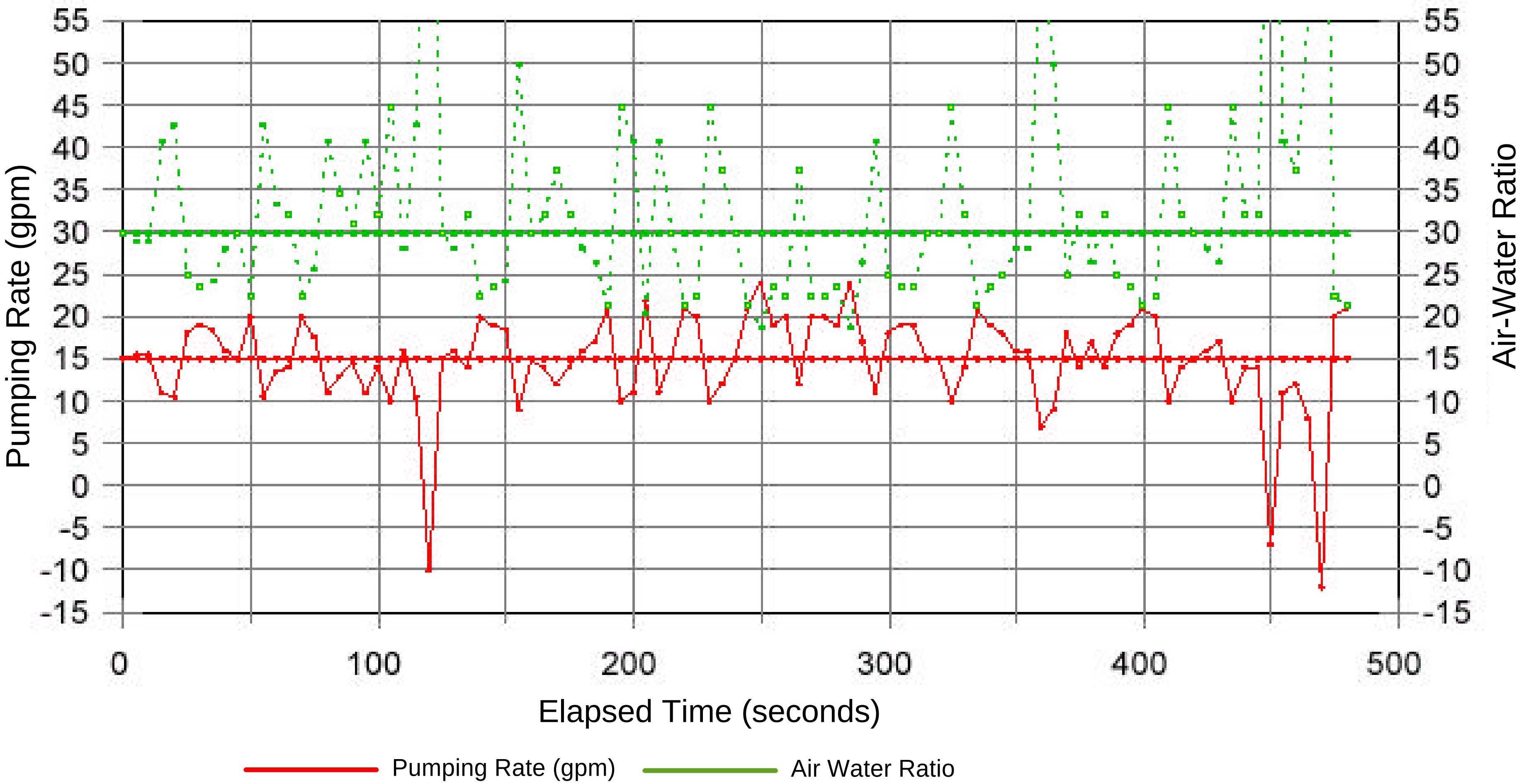
of 15 gpm and average air-to-water ratio of 30:1 (see Figure 15). It should be noted that prior to September 1998, many of the operating instruments on the NoVOCs™ system were direct-reading indicators, and data were not collected electronically. Many of the data collected during the initial operation of the system were, therefore, recorded by hand during operation and maintenance visits to the site.

The NoVOCs™ system was initially constructed with a pH control system that included an in-well submersible pH electrode, a pH signal pre-amplifier at the wellhead, a programmable proportional pH controller, and a proportional chemical metering pump. The pH control system was not configured for automatic shutdown in the event of a pH excursion. Such a shutdown was not part of the initial system design for the NoVOCs™ system demonstration or any other previous NoVOCs™ installation. pH control was maintained by adding metered amounts of 30 percent HCl to the air supply line at the wellhead during operation. The system was configured with interlock circuits to prevent system operation without a supply of acid in place.

The initial pH control objective was to maintain the pH of the treated water in the well at, or near, the pretreated groundwater pH of about 7.5. A preliminary air sparge and acid titration test was conducted on water from the site during preparation of the detailed design for the system. This test indicated that the air stripping action of the NoVOCs™ well would be expected to raise the pH of the water to approximately 8.3 after stripping. This pH rise, although not substantial compared to some highly alkaline waters of the western United States, was sufficient to raise a concern for calcite precipitation during system operation. The acid titration test was performed to support a preliminary estimate of acid consumption for pH control and for sizing the metering pump and other equipment. The results of the air sparging and acid titration tests are shown in Figures 16 and 17.

When the NoVOCs™ system was started on March 13, 1998, the pH control system indicated a wide range during the pH control cycle. The initial maximum pH was observed to be approximately pH 12.5 with a cyclical low of pH 6.95. This condition was observed for less than 24 hours from the startup and was attributed to the cycling of residual Portland cement from the bentonite-grout seal placed between the inlet and outlet screens of the NoVOCs™ well. The difference between observed pH cycles for selected periods on March 13, 1998, about 6 hours after startup, and on March 17, 1998, are shown in Figure 18. The high pH level was not observed again after the initial startup period.



gpm   gallons per minute

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 15
NoVOCs™ SYSTEM WELL PUMPING RATE VERSUS AIR TO WATER RATIO - March 16, 1998

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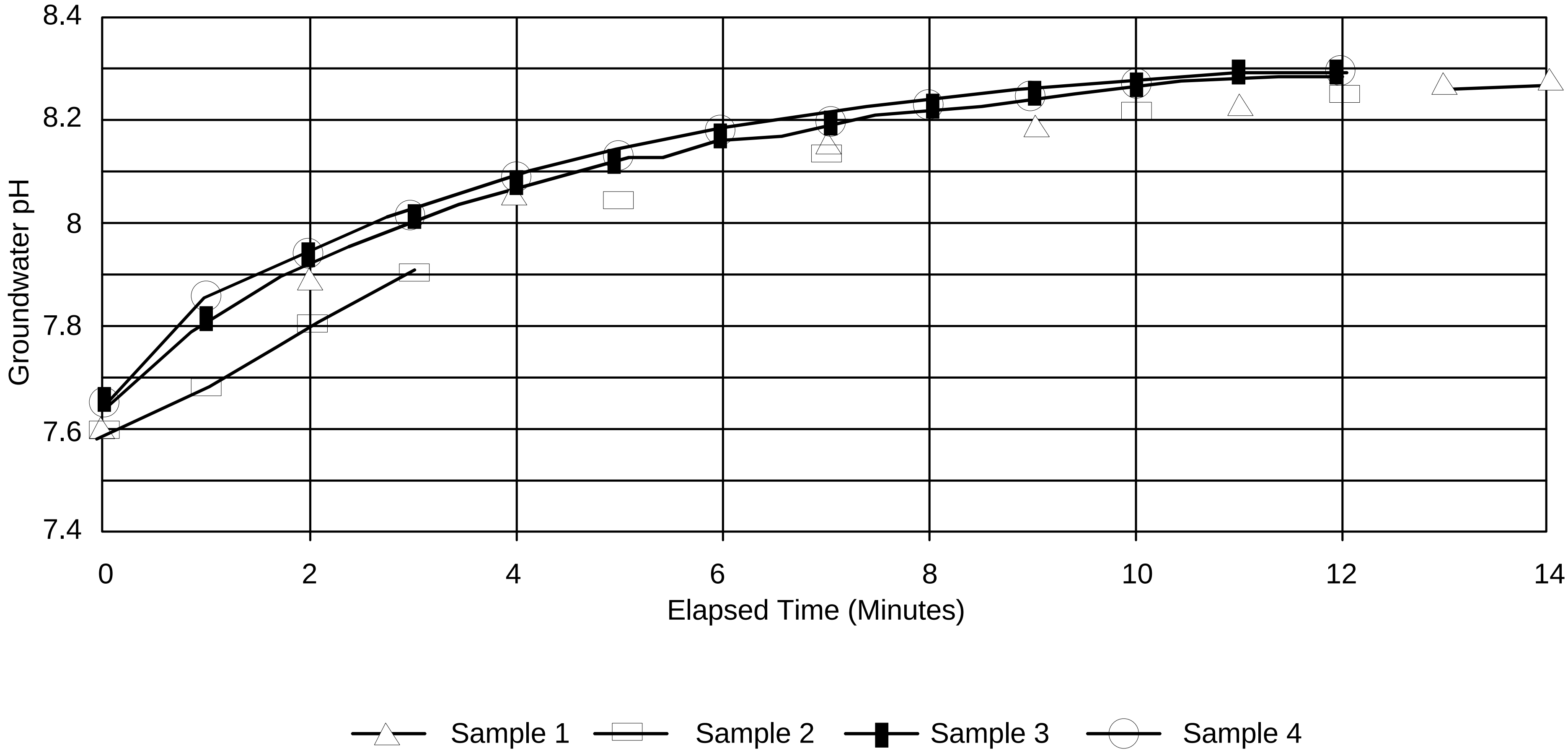
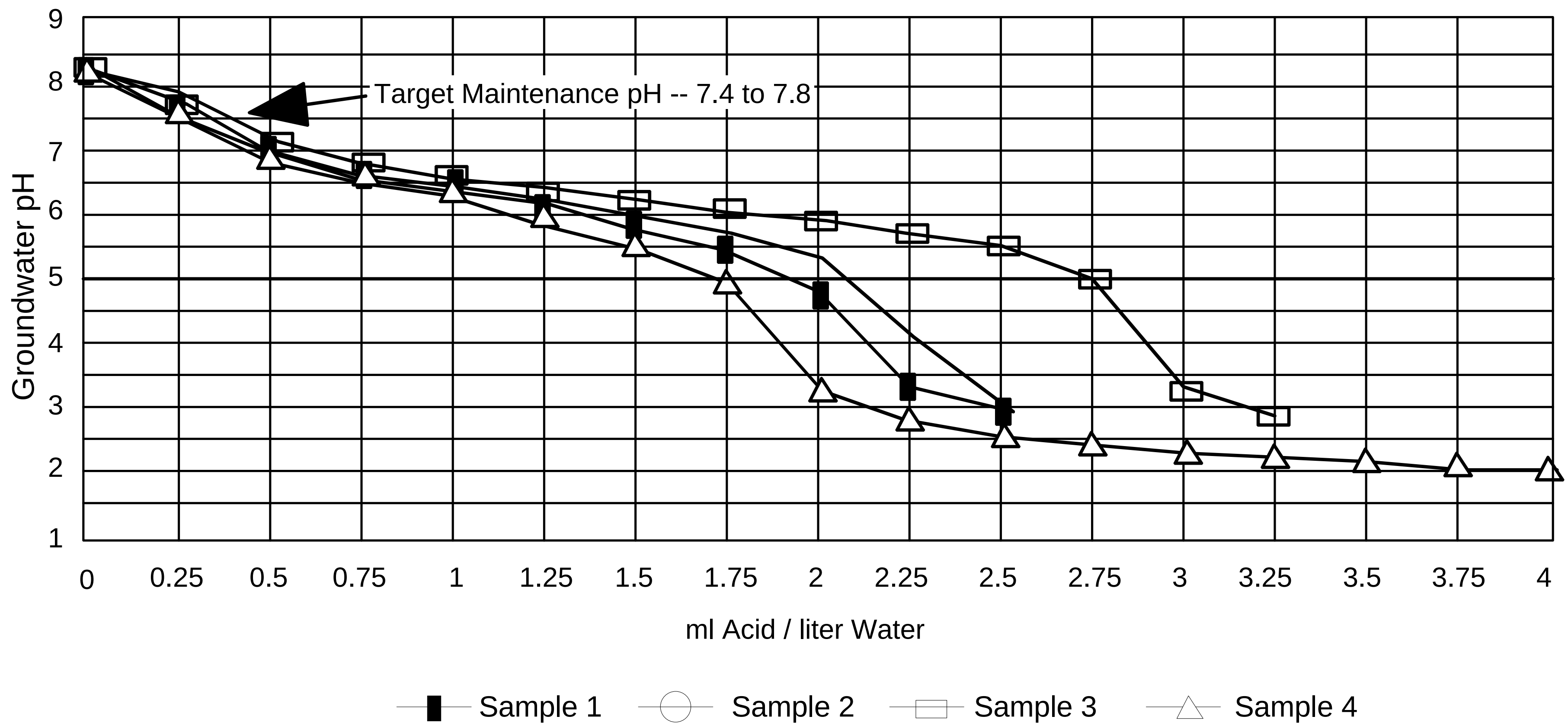


NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 16
GROUNDWATER AIR SPARGING
pH RESULTS

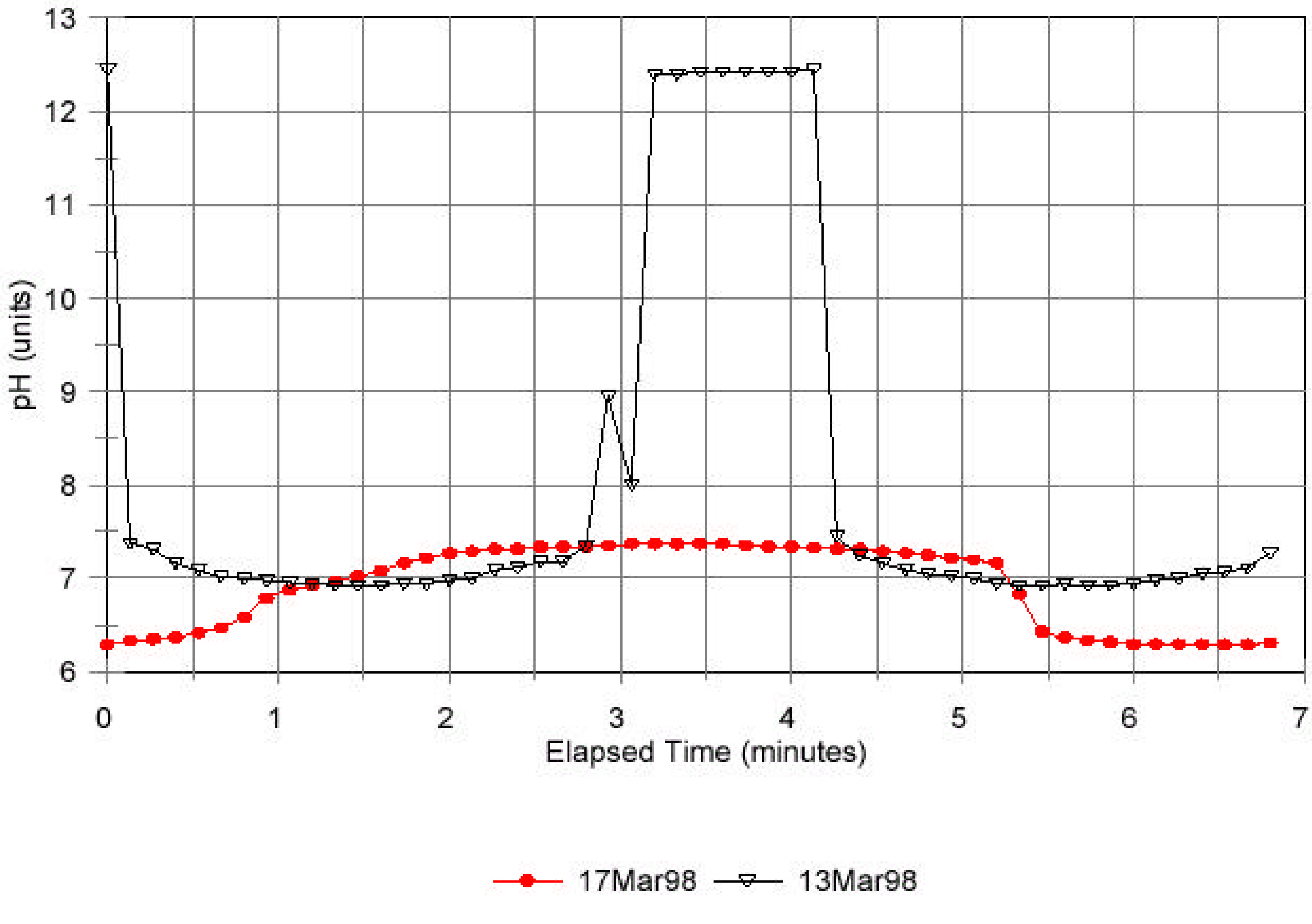
Tetra Tech EM Inc.



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 17
TITRATION TEST RESULTS

Tetra Tech EM Inc.



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 18
NoVOCs™ SYSTEM pH CYCLES
March 13 and 17, 1998

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A demonstration kickoff meeting was held at NAS North Island on March 26, 1998, with all interested parties attending. Although the Navy indicated that the system was operating satisfactorily, MACTEC requested that the system be shut down because the pH controller did not send a shutdown signal to the logic controller. The system was idle between March 26 and April 20, 1998, while MACTEC modified the system controls to provide the pH shutdown feature.

3.1.2.2 Early System Operation — April 20 through June 19, 1998

The NoVOCs™ system was restarted on April 20, 1998, after installation of the additional hardware and software required to provide automatic system shutdown on pH excursion. The NoVOCs™ well internal components were removed for a brief inspection on April 20, 1998. At this time, the internal components displayed a very slight indication of ferric hydroxide deposition. The condition of the internal components of the well can be seen in Figure 19a. The system operated continuously until May 4, 1998, when the system exhibited a high water level shutdown. The NoVOCs™ well was initially designed and equipped with a float switch placed within the well casing at the approximate elevation of the ground surface. This switch was connected to the system logic controller to provide automatic shutdown of the system in the event a rising water level within the well threatened to allow free water to enter the return air plumbing. Free water entering the system through the return airline potentially could fill the return airline and the moisture separator on the NoVOCs™ blower system and require the removal of a substantial quantity of contaminated water from the system. The system was restarted shortly after the May 4, 1998, shutdown; however, the high water level condition was again observed on May 8 and 9, 1998.

Bechtel staff and subcontractors diagnosed the problem on May 13, 1998, by placing miniature transducer-data logger devices in the inlet and outlet piezometers of the NoVOCs™ well and within the annular space between the well casing and the eductor pipe. With these monitoring devices in place, the system was restarted and allowed to run until the high-level condition and automatic shutdown was observed. Figure 20 shows the relative water levels measured in the three locations. The plotted lines indicate the expected drawdown in the intake piezometer and anticipated rise in the recharge piezometer, both of which remained fairly stable during the diagnosis run. The water level in the annulus, however, started out substantially higher than that of the recharge piezometer and increased steadily until a high-level shutdown was induced (see Figure 20, time period 1600 hours to 2045 hours).

Photograph 19a: Well Air Unit

Photograph 19c: Well Internals

Photograph 19b: Well Educator Pipe

Photograph 19d: Biofouling Sample

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 19
NoVOCs™ WELL INTERNALS PHOTOGRAPHS

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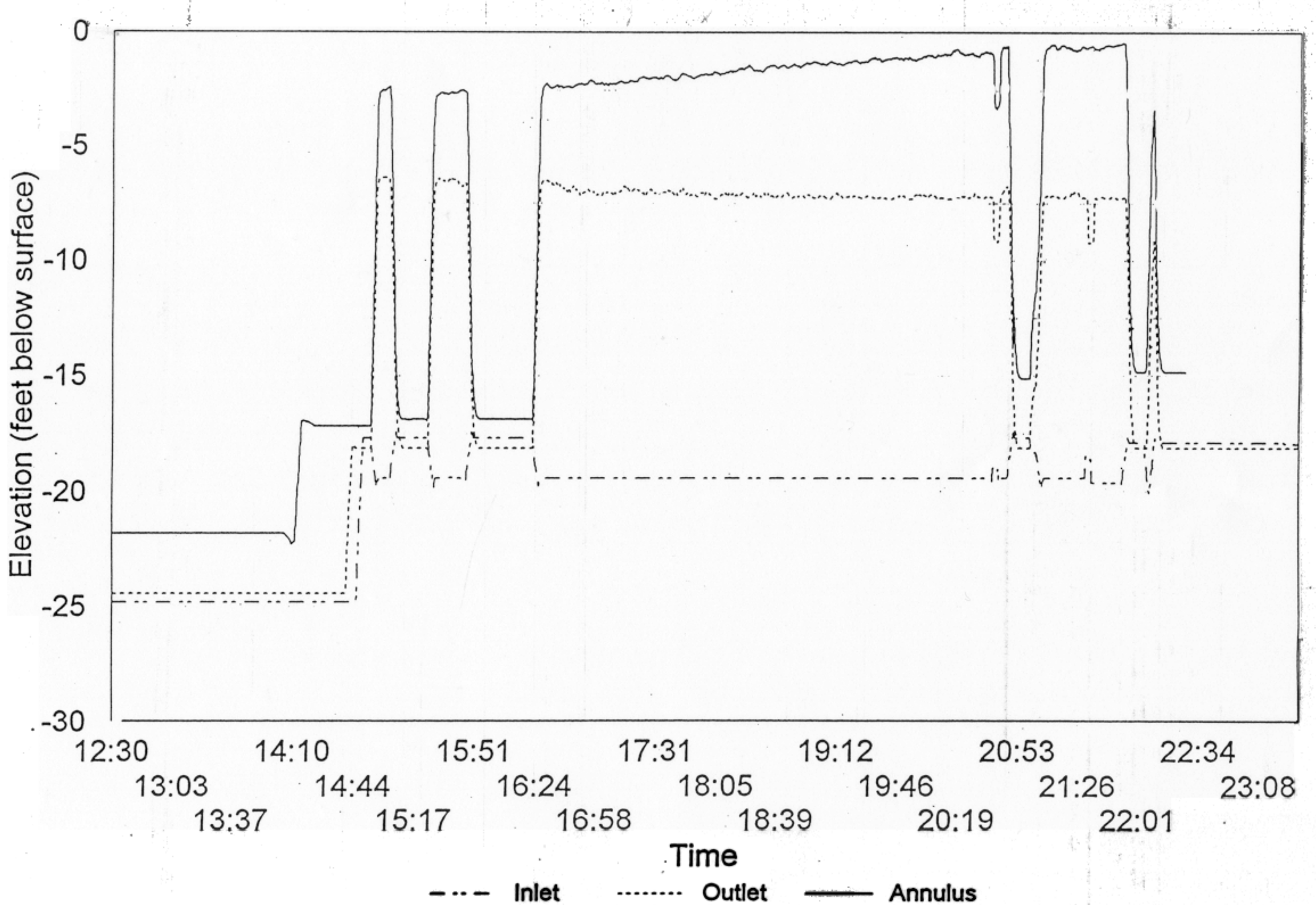

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 20
WATER LEVEL IN THE NoVOCs™ WELL
May 13, 1998

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The fluid inside of the well annulus is a dynamic air-water mixture of varying content; therefore, the observed level in the annulus is expected to be somewhat higher than the dynamic water level in the recharge piezometer located within the filter pack outside of the well casing. The observed increase in the annulus level over the operating period shown in Figure 20, however, is not normal. The first high-level shutdown was observed at about 2045 hours. The system was then restarted, and another shutdown occurred within 10 minutes. These data indicated that the problem was indeed a condition of high level within the well, and the well was subsequently disassembled to examine the situation.

As well internals were removed from the well on May 14, 1998, the internal parts were found to be heavily coated with orange ferric hydroxide slime. Figure 19b shows the ferric hydroxide covering the airline and upper internal components. At the time the photograph in Figure 19b was taken, the ferric hydroxide was already substantially dehydrated. All of the internal components, including the 5-inch-diameter eductor pipe were removed from the well. The eductor pipe following removal from the well is shown in Figure 19c. The ferric hydroxide deposition was confined to the portions of the well that were either directly aerated during airlift pumping or where aerated water flowed through the well structure. All well internal components were cleaned with HCl to remove the iron precipitates prior the reinstallation in the well.

While the well internals were removed, the well was redeveloped on May 15 and 16, 1998. Well redevelopment consisted of bailing to remove a small amount of sand that had accumulated in the bottom of the well followed by pumping the lower screened interval at varying rates up to about 13 gpm. About 2,000 gallons of water were removed during redevelopment. The water from the lower screened interval was observed to be clear with measured turbidity of less than 5 nephelometric turbidity units (NTU). The submersible pump was removed from the well and an inflatable test plug was then placed in the well at an elevation below the recharge screen. The plug was inflated to isolate the upper screen from the lower screen, and the submersible pump was placed in the upper screen zone. The upper zone was pumped at varying rates, while the screened interval was simultaneously washed with a high-pressure water jet. After development, the water produced from the upper zone was also observed to be clear with turbidity less than 5 NTU. During well development, the upper zone (that is the recharge screen zone) displayed drawdown of 2 feet at 5 and 8 gpm, 3 feet at 13 gpm, and 8 feet at 50 gpm. The observed drawdown during development was not expected to represent a steady state condition because of the short duration of the pumping events.

The NoVOCs™ well was re-assembled and restarted on May 16, 1998. The system operated continuously with only brief stops for maintenance and sampling until May 26, 1998. At this time, the diagnosis of erratic pH indicated that the pH pre-amplifier was not functioning normally. Although the system was still operating at the time, it was shut down until a replacement pre-amplifier could be obtained and installed. The pre-amplifier was installed on June 1, 1998, and the system was restarted. A low pH shutdown was experienced after only a few hours of operation. The pH supply was adjusted and the airline submergence was reduced by about 1 foot (from 10.5 feet below static water level to 9.5 feet below static water level). The system was restarted on June 3, 1998. The system operated in this configuration at an indicated pumping rate of about 2 gpm until June 10, 1998, when the submergence was increased to 10.5 feet to increase the pumping rate. After a few hours of operation, the system again shut down because of a high water level within the well. The submergence was reduced to 9.5 feet below static water level again and the system was restarted. The system operated in this configuration until June 19, 1998, when a high water level in the well induced an automatic shutdown. Bechtel staff removed some readily accessible internal components from the well and again observed substantial accumulation of ferric hydroxide slime.

The system was operated continuously for 2 more days on June 24 through 26, 1998, but the need to implement some iron precipitation control was recognized. On June 27, 1998, the NoVOCs™ system was shut down for technical review and assessment of alternatives for precipitation control.

3.1.2.3 Aquifer Testing and System Modification — July through September 1998

After the system was shut down on June 27, 1998, MACTEC undertook a redesign and reconfiguration of the NoVOCs™ well internals. The design and fabrication of the new components took from July 1 through September 23, 1998. During this period, a series of aquifer pump tests at the site were conducted by EPA to provide additional information regarding hydrologic conditions at Site 9. The results of the aquifer tests are summarized in Section 3.2.2.5.

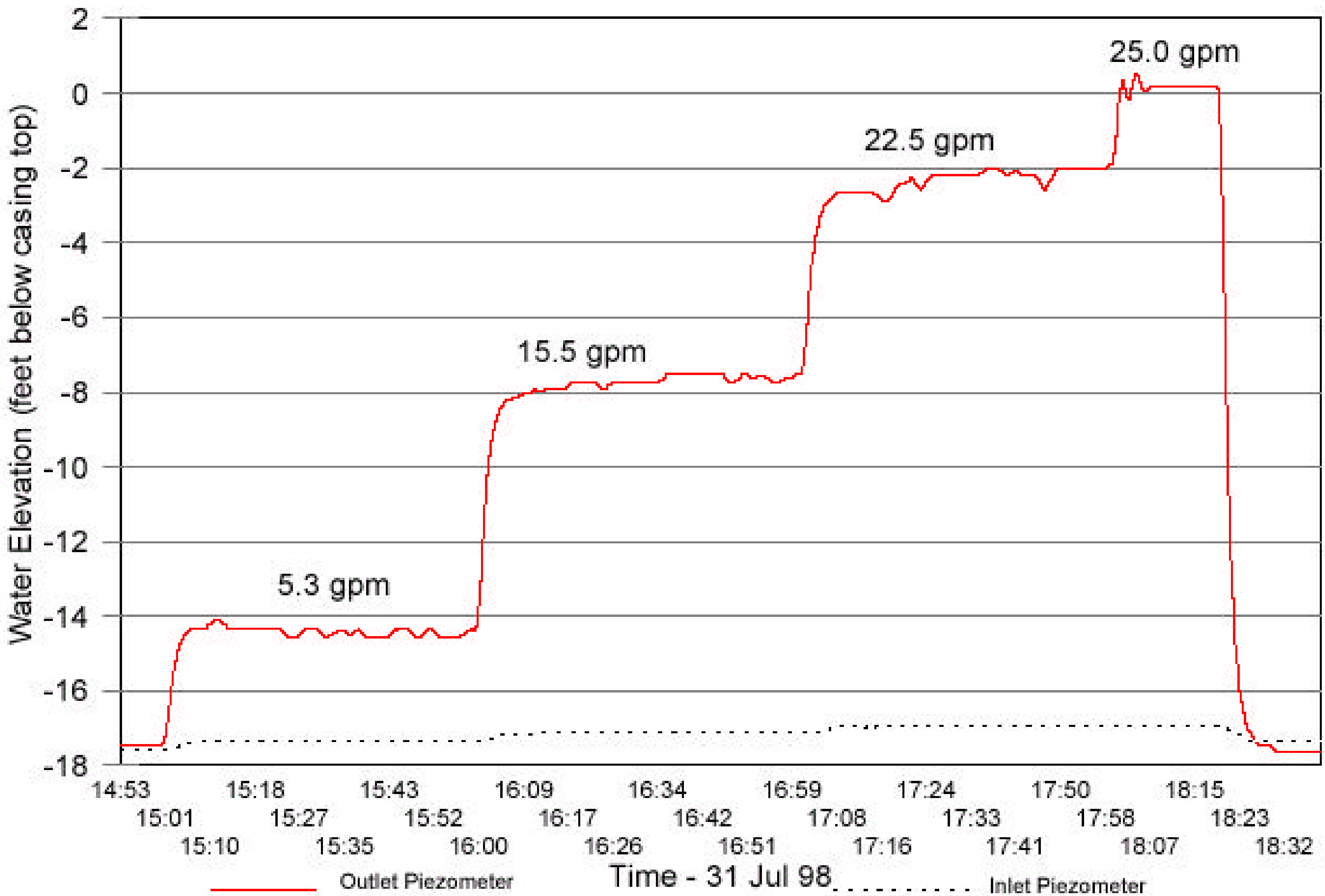
Down-hole Camera Survey. A down-hole camera survey of the NoVOCs™ well was conducted prior to redeveloping the well and performing the aquifer tests. The NoVOCs™ system had not been operated for a month before the down-hole camera survey and may not accurately reflect the condition of the operating well. The camera survey revealed the presence of biological fouling of the intake (lower) screen of the NoVOCs™ well in addition to large volumes of hydrated ferric hydroxide flocs. Because the upper screen was scraped clean during removal of the internal well components, no visual indications of biofouling in the upper (recharge) screen were observed during the video survey. In reviewing the operating history of the NoVOCs™ well, it seems likely that biofouling, combined with the formation of hydrated ferric hydroxide from direct aeration of water in the well, contributed to the observed fouling of the recharge screen and subsequent high water level conditions observed. A sample of water from the well was submitted by Bechtel for bacteriological screening. The results of the screening confirmed the presence of a complex of microorganisms (see Section 3.1.3).

In addition to the traditional aquifer characteristics determined by the aquifer tests, two other important pieces of information were collected during the aquifer tests. These were confirmation of the recharge capacity of the upper screen of the NoVOCs™ well, and verification of calibration of the in-well orifice plate flow sensor.

Recharge Test. A recharge test of the upper (outlet) screen of the NoVOCs™ well confirmed that the outlet zone was capable of accepting water at a rate of 22.5 gpm with a standing water level in the well of about 2 feet below local grade and 25.0 gpm with a water level in the well at local grade. The water levels measured in the recharge piezometer during the recharge test are shown in Figure 21.

Down-hole Flow Sensor Test. The NoVOCs™ well initial design and construction included an in-well flow sensor consisting of a 1.5-inch-diameter orifice plate placed in a section of 2-inch-diameter pipe. This pipe section was fitted with a rubber seal and located inside of the eductor pipe below the air sparger in a configuration that routed the entire water flow within the eductor pipe through the flow sensor prior to aeration. The original system design included flexible pressure lines connected to radius taps above and below the orifice plate, extending upward through the well seal and outside of the wellhead. These pressure lines were connected to a solid state differential pressure transducer at the wellhead. The transducer received an excitation signal from, and transmitted a pressure signal to a digital panel meter located in the NoVOCs™ mechanical system trailer.

The panel meter was calibrated over a range of 0 to 40 inches of water differential pressure using the specific transducer at the well. The panel meter displayed the differential pressure across the orifice plate directly in units of inches of water differential. The indicated differential pressure was converted to an



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 21
NoVOCs™ WELL
RECHARGE TEST RESULTS

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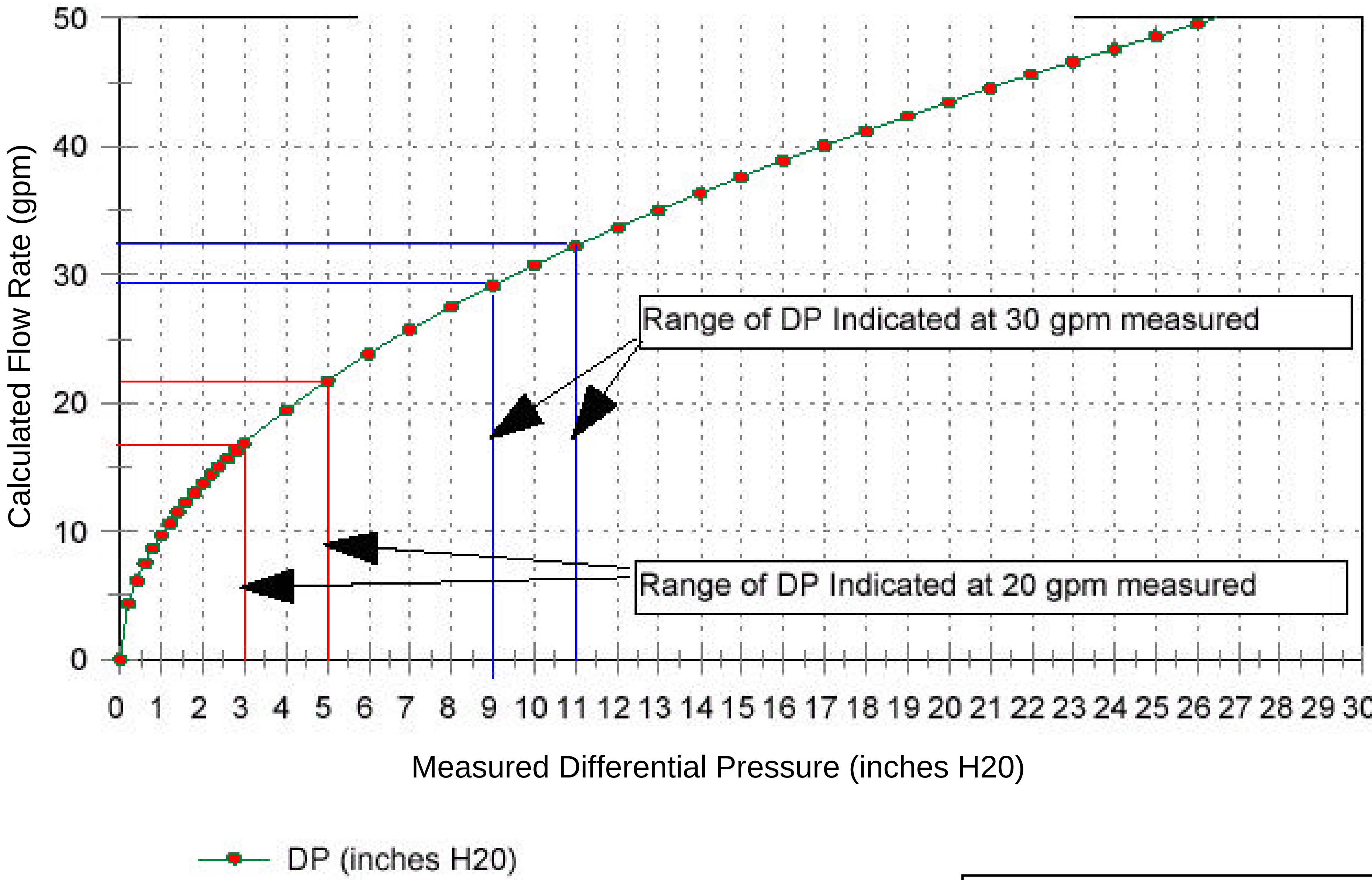
in-well flow rate in gpm using a calibration curve derived for this specific orifice plate configuration. This system initially appeared to provide satisfactory indication of the NoVOCs™ well pumping rate; however, the system did exhibit short-term cyclical variation (over periods of minutes) and substantial drift over a period of hours to days. Some of the drift was attributed to leaks in the pressure lines from the taps to the transducer. This cyclical and variable behavior lessened confidence in the flow indication.

During the aquifer pumping tests with the well internals removed, Bechtel subcontractors attached the flow sensor to the end of the submersible pump discharge pipe and measured the indicated differential pressure across the orifice plate. The differential pressure was measured using an analog differential pressure gauge. The differential pressure across the orifice plate was observed and recorded at two known, measured constant water flow rates. The results of the flow sensor check are shown in Figure 22. At a known pumping rate of 20 gpm, the flow sensor indicated a differential pressure ranging from 3 to 5 inches of water, corresponding to an indicated flow rate of about 17 to 21 gpm. At a known pumping rate of 30 gpm, the flow sensor indicated a differential pressure ranging from 9 to 11 inches of water, corresponding to an indicated flow rate of 29 to 32 gpm.

The existing flow sensor was re-installed as part of MACTEC's redesign activities. The pressure tap lines, however, were subsequently connected to an uncalibrated transducer scaled from 0 to 150 inches of water with output to a data logger. The operating pressure range of the orifice plate was within the noise level of this transducer configuration. Subsequent measurements of differential pressure across the orifice plate confirming the cyclical nature of indicated flow rate were made in December 1998 and January 1999 using a calibrated pressure data logger (see Section 3.1.2.5).

NoVOCs™ Well Redesign and Configuration. During this period, MACTEC assembled modified components for installation in the well after completion of the aquifer tests. Because of the presence of biofouling organisms in the well, MACTEC included a system to inject a biocide in the well re-configuration. Two commercial chemical amendments manufactured by Betzdearborn Inc., were selected by MACTEC for addition to the NoVOCs™ system:

1. **<u>Depositrol PY 505</u>, a hydroxylated copolymer dispersant.** The purpose of Depositrol PY 505 is to prevent flocculation and maintain the colloidal state of ferric hydroxide molecules formed by direct aeration of ferrous iron in the groundwater. This material was



DP	Differential Pressure
gpm	gallons per minute

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 22
ORIFICE PLATE FLOW SENSOR CALIBRATION CURVE

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to be delivered by a metering pump into the NoVOCs™ well at a depth below the air sparger to allow mixing in the well casing. The manufacturer's recommended application rate for Depositrol PY 505 was 15 parts per million (ppm) or 0.1 pounds of product per 1,000 gallons of water treated.

2. **ENTEC 367, a broad spectrum bromine/chlorine microbiocide.** The primary active ingredient of ENTEC 367 is 1-bromo-3-chloro-5,5-dimethylhydantoin. This material was to be delivered by a timed metering pump to the filter pack outside of the intake screen of the NoVOCs™ well through a tube inserted into the intake piezometer. The manufacturer's recommended application rate for ENTEC 367 was 12 ppm for a period of 6 hours per day.

Additional modifications made to the NoVOCs™ well are depicted in Figure 10c and are summarized below:

- The eductor pipe water discharge point was raised to grade elevation.
- The wellhead casing was extended to about 5 feet above grade elevation using 12-inch-diameter, Schedule 40 PVC pipe.
- Chemical amendment addition lines were added to permit injection of the pH adjustment and iron dispersant chemicals below the air sparger.
- One additional pressure tap line was added to allow monitoring of the level of the air-water mixture in the well annulus between the well casing and the eductor pipe.

Configuration of the well for addition of the microbiocide and iron dispersant required placement of additional chemical supply drums and metering pumps. The existing acid metering system and the two new metering systems were relocated from the mechanical system trailer site to the vicinity of the NoVOCs™ wellhead. This required extension of line power to a new service panel near the wellhead.

MACTEC installed an enhanced programmable logic controller to support the new metering systems and to resolve some operational difficulties experienced with the initial system logic controller during early operation. This new controller included multi-channel data logging capability and remote monitoring and data download. The new controller and software performed admirably for the duration of the demonstration period.

3.1.2.4 NoVOCs™ Well Operation after Reconfiguration — September 24 through October 30, 1998

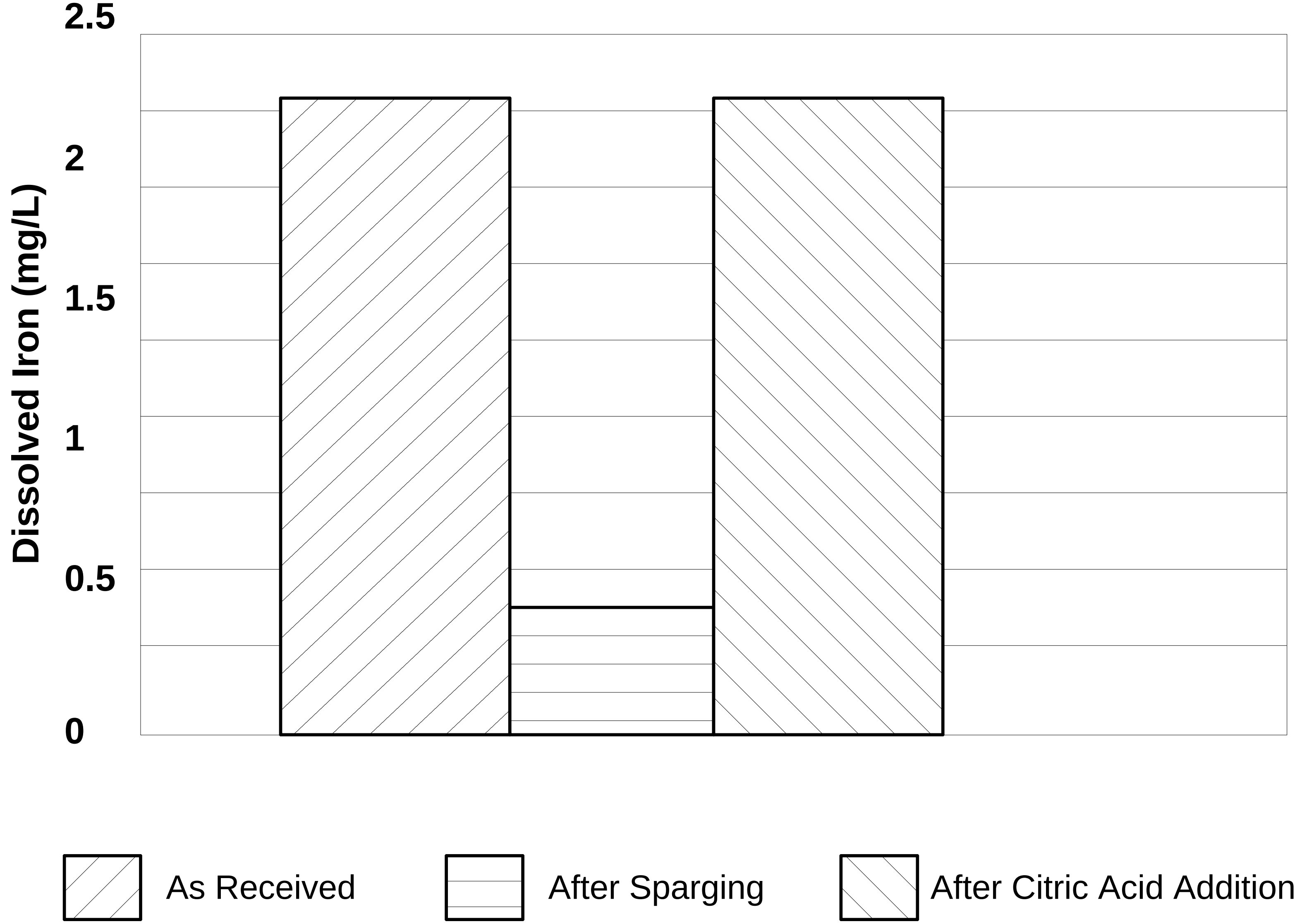
On September 24, 1998, the reconfigured NoVOCs™ system was started. Some initial problems were encountered with restarting the Thermatrix unit after the 3-month period of nonoperation. MACTEC personnel operated the NoVOCs™ system under various conditions during this period to attempt to maximize the pumping rate in the well. The operation of the system from September 24 to October 30, 1998, was interrupted on numerous occasions by high water level conditions in the NoVOCs™ well and on four occasions by off-normal conditions in the Thermatrix unit. During this time, the precipitation control amendment was added to the system, and the microbiocide was added to the well at varying rates.

On October 27, 1998, the NoVOCs™ system was shut down because of a rising water level in the well. Accessible internal components were removed and observed to be coated with hydrated ferric hydroxide slime. Bechtel staff concluded that the well was again exhibiting fouling of the recharge screen. The system was operated again for brief periods from October 28 through 30, 1998, during which the system experienced repeated high water level shutdowns. MACTEC decided to discontinue their participation in the demonstration, and the system was idle from October 30 through December 4, 1998.

3.1.2.5 Final Configuration and Operation — December 4, 1998 through January 4, 1999

The Navy decided to make a final attempt to operate the NoVOCs™ system at Site 9. Bechtel staff and subcontractors developed a system restart strategy and evaluated the system. The well internals were inspected and found to be heavily fouled by ferric hydroxide precipitation. Based on observations by Bechtel staff of a brief response of decreased water level in the NoVOCs™ well following addition of a small quantity of additional HCl during the October 1998 operation period, Bechtel staff and subcontractors decided to attempt a chemical development of the NoVOCs™ well.

Well Evaluation and Testing. Bechtel subcontractors conducted bench tests during June and November 1998 on the effectiveness of citric acid in controlling ferric hydroxide precipitation following aeration of groundwater from Site 9. The bench tests indicated that citric acid could be very effective in controlling iron precipitation as well as providing the required pH control for the NoVOCs™ process. An example of the action of citric acid solution on the dissolved iron content of a groundwater sample from Site 9 is shown in Figure 23. This figure shows the results of three analyses of dissolved iron in a water sample.



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 23
IRON PRECIPITATION TEST RESULTS

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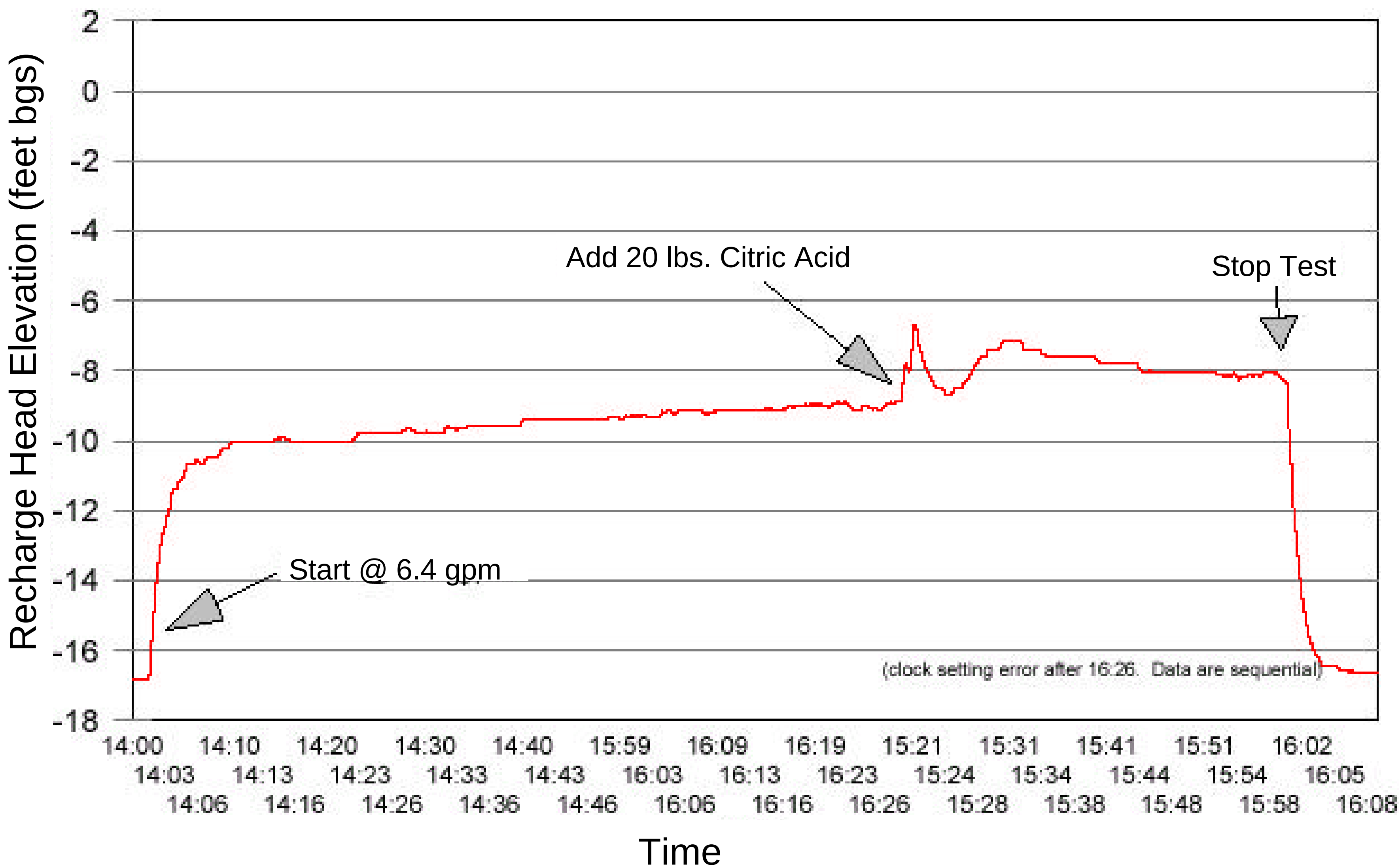
The first analysis is the as-received content of dissolved iron (2.2 milligrams per liter [mg/L]). The water sample was then aerated in an open beaker using an air pump, tubing, and an air stone. After aeration, visible ferric hydroxide flocs were seen in the beaker. A decanted supernatant sample contained only 0.42 mg/L of dissolved iron. The same aerated sample was then treated with citric acid solution and retested, indicating that the dissolved iron content in the sample was once again at the pre-aeration concentration of 2.2 mg/L.

Before final configuration operation, the precipitation control system was modified for addition of 20 percent citric acid solution because the commercial Depositrol PY 505 had been shown to not provide satisfactory iron precipitation control at the added rate. In addition, the NoVOCs™ well was injected with about 5 gallons of HCl. This solution was agitated in the well casing and allowed to sit for several hours before testing its effect on the well.

On December 2, 1998, a recharge test was conducted on the NoVOCs™ well. This test was conducted by adding water to the well annulus and measuring the recharge elevation height in the recharge piezometer. The results of the test are displayed graphically in Figure 24. Water was added to the well annulus at a constant rate of 6.4 gpm. The water level quickly increased to a level substantially above the level expected for that recharge rate, based on the recharge rate versus recharge head observed during tests in July 1998. The water level continued to rise gradually during the test, indicating reduced recharge capacity. After about 2 hours of recharging the well at 6.4 gpm, 20 pounds of crystalline citric acid were added directly to the well annulus. After another 30 minutes of recharging, the water addition was stopped and the water recharge rate was observed.

Measurement of the well recharge rate after citric acid treatment indicated that the recharge rate had improved, apparently through dissolution of ferric hydroxide precipitates within the well. The recharge portion of the test curve shown in Figure 24 displays characteristics very similar to the recharge portion of the test curve from July 31, 1998 (see Figure 21). This test indicated that the treatment was sufficiently effective to consider starting the NoVOCs™ system using citric acid for iron precipitation control.

NoVOCs™ System Reassembly and Restart. The NoVOCs™ well was reassembled on December 3 and 4, 1998. The in-well flow sensor was connected to an analog differential pressure gauge for direct reading. The high-level float switch was re-installed within the well casing, and the system was restarted



gps gallons per minute
bgs below ground surface

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 24
NoVOCs™ WELL RECHARGE TEST
DECEMBER 2, 1998

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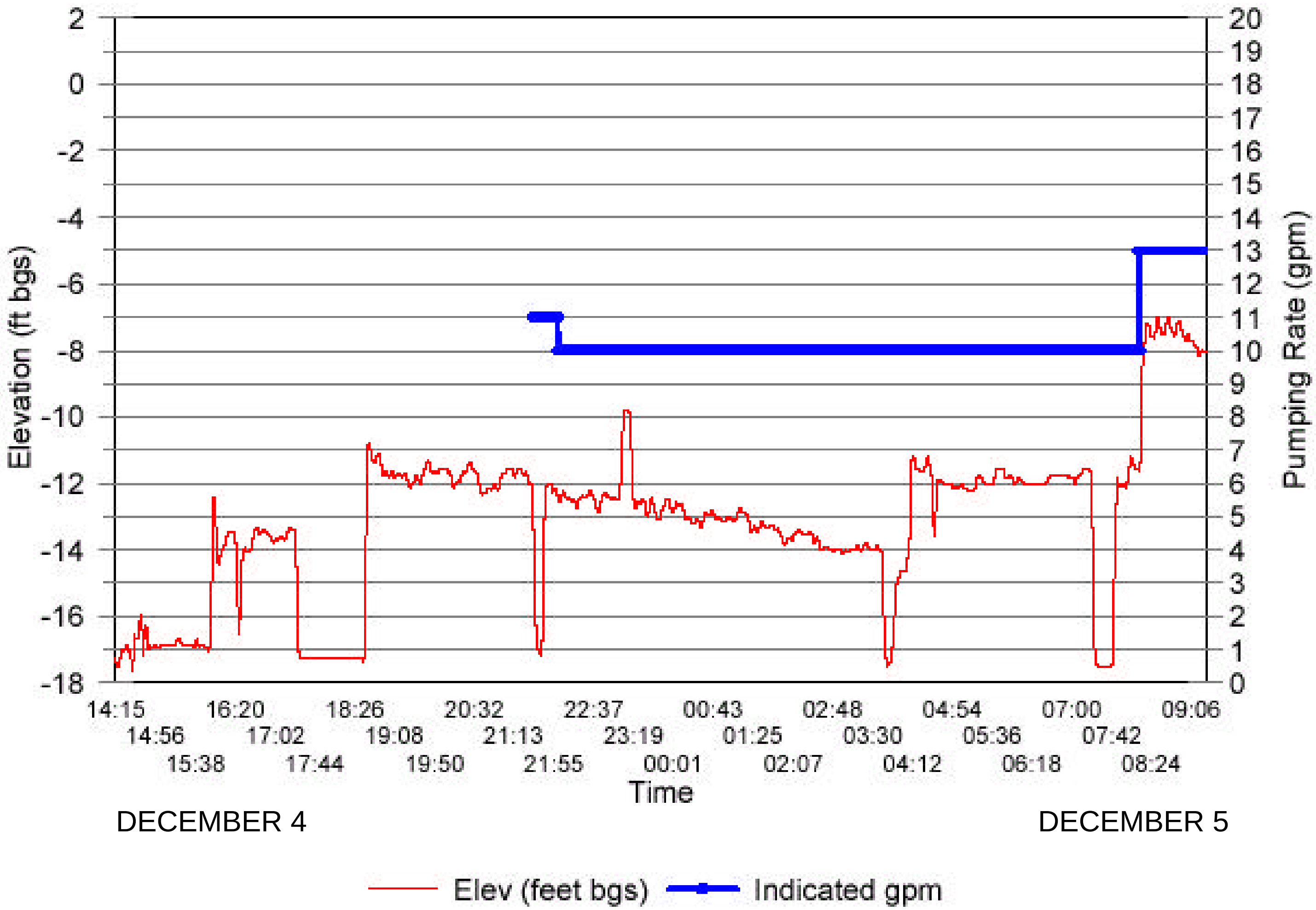
at about 1600 on December 4, 1998. The system was operated overnight with higher than normal injection rates of citric acid solution and HCl to maintain a pH between 1 and 2 within the well. The system exhibited satisfactory water levels and pumping rates and the acid injection rate was gradually reduced until almost no HCl was used and only citric acid was added to maintain the well water pH between 4 and 6. The system was monitored continuously during this startup period to ensure that the recharge level remained in an operable range and responded proportionally to changes in pumping rate. Charts showing the dynamic water level in the recharge piezometer and the indicated pumping rate for this period are shown in Figures 25a through 25d. The system was shut down manually four times to make adjustments during the first 20 hours of operation, but the water level remained stable and responsive to the pumping rate (see Figure 25a). The Thermatrix unit displayed low temperatures at about 0930 on December 5, 1998, and was off line until 1458, when the NoVOCs™ system was restarted (see Figure 25b). The system then operated continuously at an indicated pumping rate of 10 gpm with a stable recharge head in the recharge piezometer until 1100 on December 7, 1998, when the Thermatrix unit went off line.

The system was shut down while the Thermatrix burner head and associated piping were repaired. The carbon steel burner head and some associated stainless-steel piping had been damaged by corrosion, apparently from the HCl produced by the oxidation of the chlorinated compounds in the NoVOCs™ offgas stream.

Final Operating Period. The NoVOCs™ system was restarted at about 1630 on December 10, 1998. At this time, the water level transducer for the recharge piezometer was connected to the system logic controller for data logging. During the system testing and startup in December, the recharge piezometer had been monitored using a stand-alone transducer and data logger unit. The system was left in unattended operation on December 10, 1998, with the operating parameters shown in Table 4.

As part of the final demonstration effort, the Navy established a set of performance criteria that the NoVOCs™ demonstration system must meet in order to continue the demonstration. These criteria included the following primary requirements:

1. The NoVOCs™ system must be operational by December 10, 1998, at an indicated pumping rate of 10 gpm or greater.



bgs below ground surface
gpm gallons per minute

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 25a
NoVOCs™ WELL RECHARGE PIEZOMETER WATER LEVEL - DECEMBER 4 AND 5, 1998

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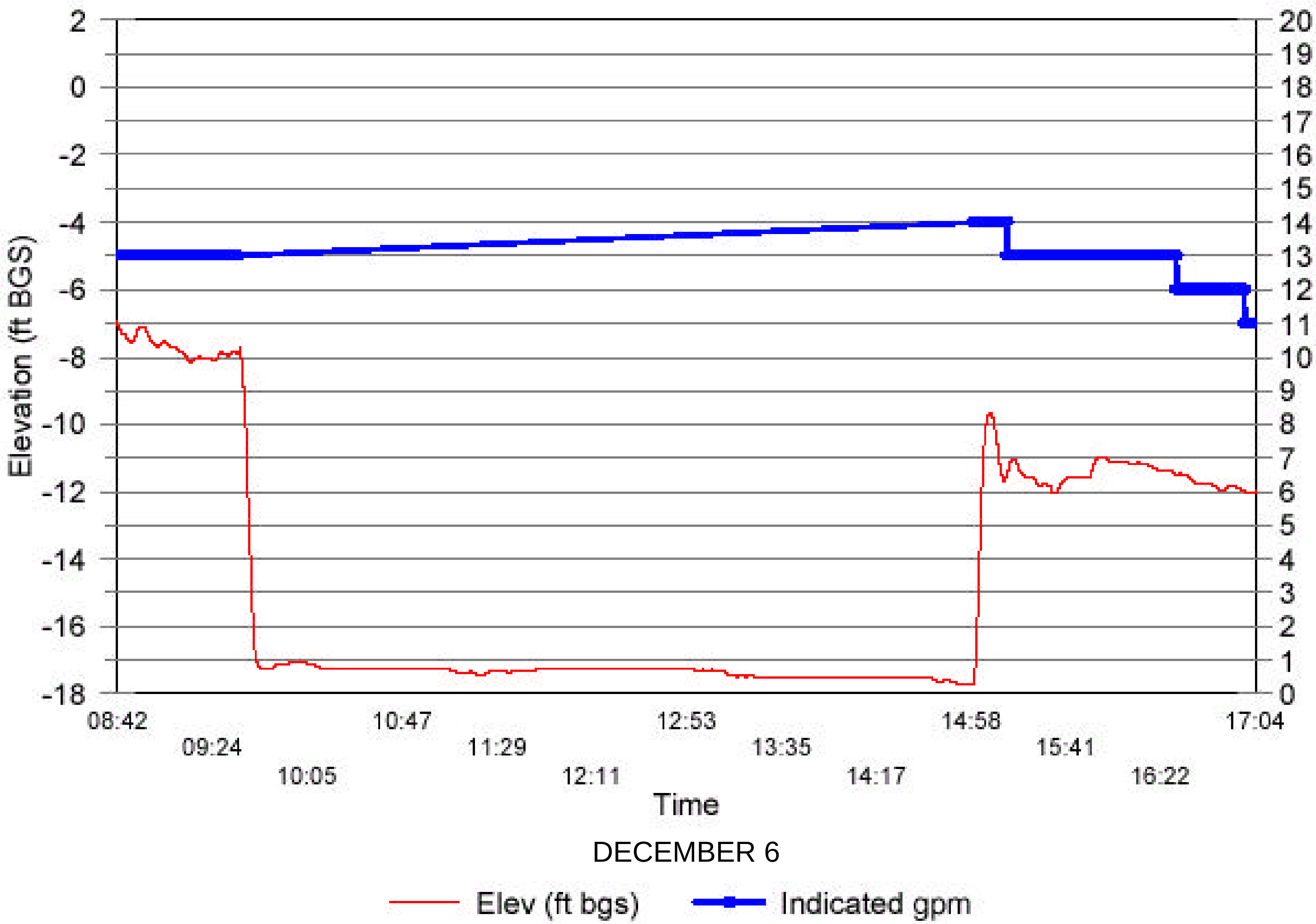

bgs below ground surface
gpm gallons per minute

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 25b
NoVOCs™ WELL RECHARGE PIEZOMETER WATER LEVEL - DECEMBER 6, 1998

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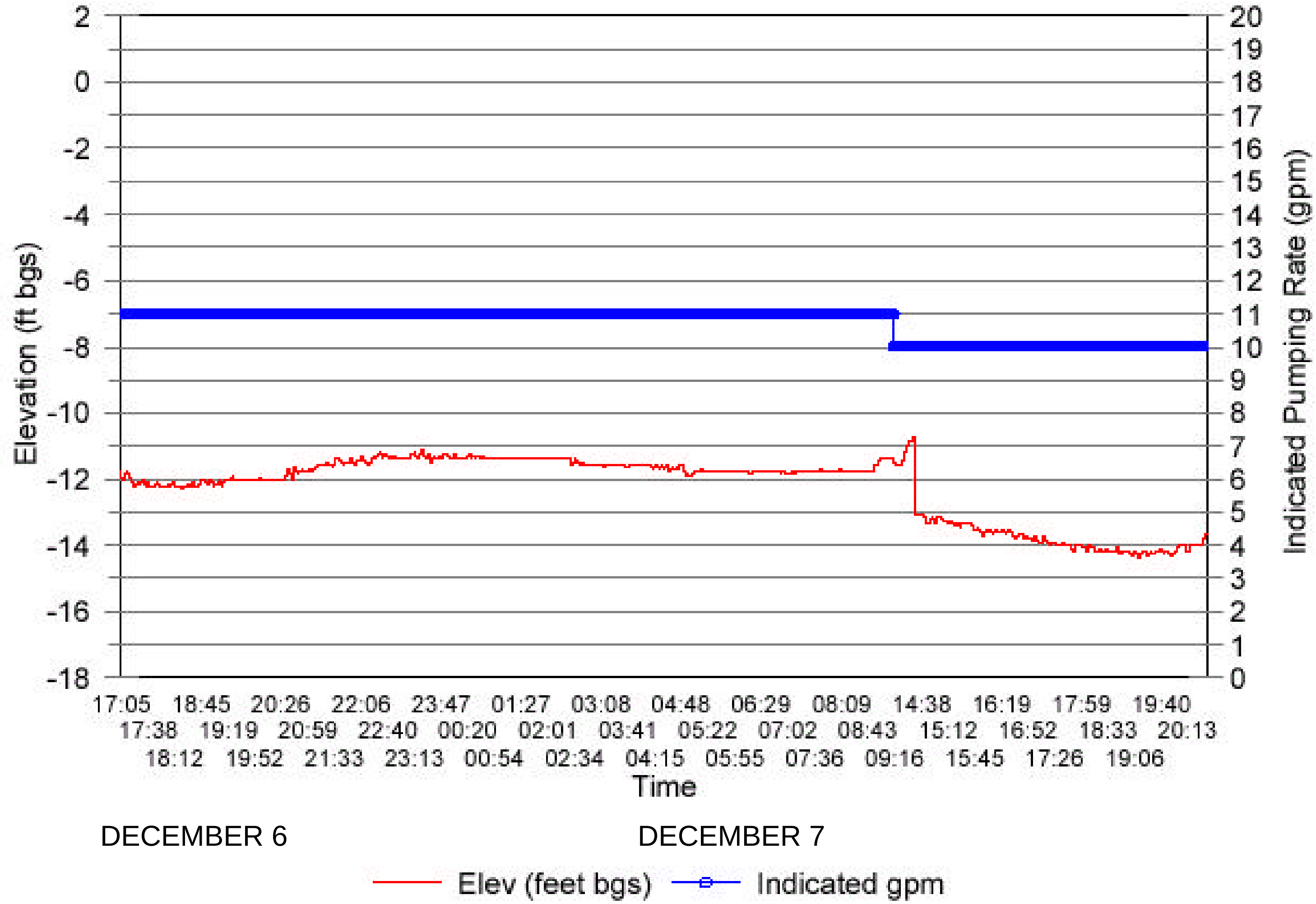

bgs below ground surface
gpm gallons per minute

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 25c
NoVOCs™ WELL RECHARGE PIEZOMETER WATER LEVEL - DECEMBER 6 AND 7, 1998

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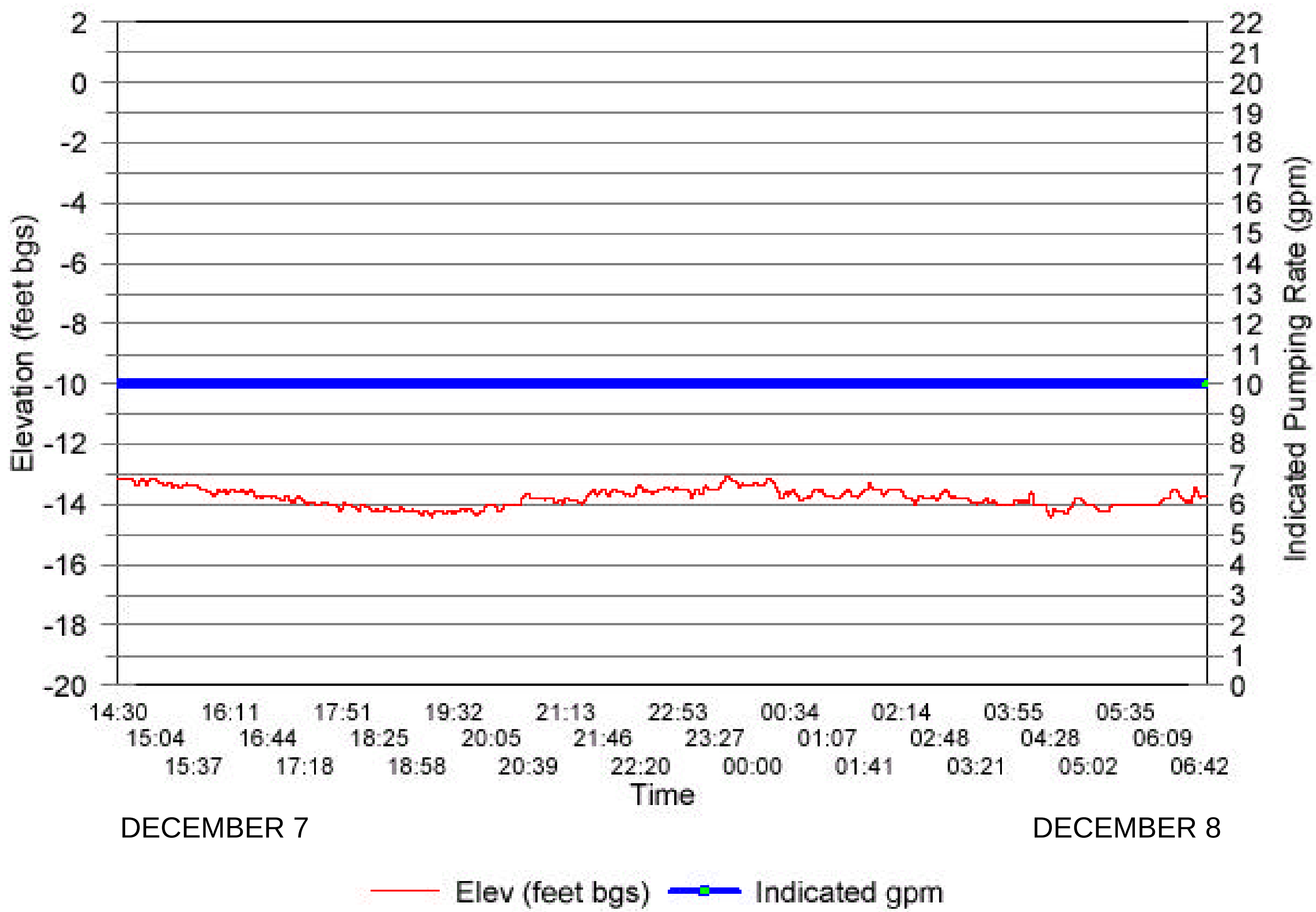

bgs below ground surface
gpm gallons per minute

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 25d
NoVOCs™ WELL RECHARGE PIEZOMETER WATER LEVEL - DECEMBER 7 AND 8, 1998

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TABLE 4

NoVOCs™ SYSTEM OPERATING PARAMETERS — DECEMBER 10, 1998
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Parameter	Normal Setting/Operating Range (Set Points)	Indicated Range During Final Operation
Initial Airline Submergence	8 to 11 feet below SWL (no set point)	10 feet below SWL
Supply Air Flow	40 to 60 scfm (Shutdown at 0 scfm)	50 scfm (49 to 55 indicated)
Supply Air Pressure	120 to 200 inches WC (Shutdown at 210 inches WC)	129 to 130 inches WC
Supply Air Temperature	100 °F to 180 °F (Shutdown at 210 °F)	130 °F
Supply Air Suction	-5 inches WC (Service filter if -10 or less)	-5 inches WC
pH	2.5 to 7.5 pH units (Shutdown if </= 0 or >/= 8)	3.6 to 7.2 pH units
Precipitation Control	As required	Citric acid — 20 percent solution
Biofouling Control	Biocide addition 6 hours/24 hours (1 hour/24 hours)	As programmed (not adjustable)
Wellhead Supply Air Pressure	1.5 to 4.0 psi	2.9 to 3.3 psi
Wellhead Return Air Suction	Net negative pressure	-5 +/- 3 inches WC
Indicated Well Pumping Rate	5 to 15 gpm	10 gpm (range 8 to 13 gpm)
Thermatrix Suction Blower Speed	55 to 60 Hz	60 Hz
Thermatrix Suction	-10 to -30 inches WC	-25 inches WC

Notes:

SWL Static water level
scfm Standard cubic feet per minute
gpm Gallons per minute
psi Pounds per square inch
Hz Hertz
WC Water column

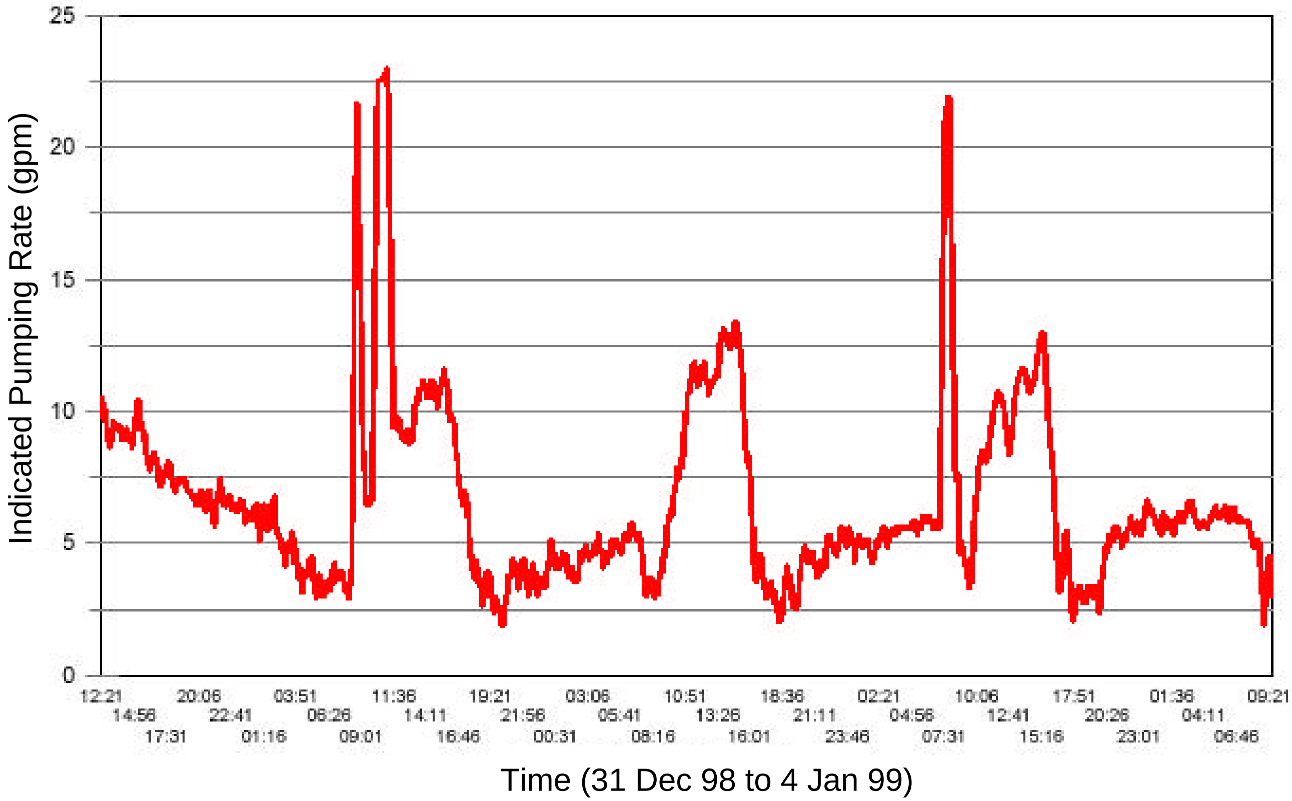
2. If the system were to go off line and not return to operation within 24 hours of a shutdown for any reason, the demonstration would be terminated.

Bechtel staff and subcontractors were able to start operation of the system within the required timeframe and maintain operation of the system an average of 91 percent of the time for the period from December 10, 1998, through January 4, 1999. This was the longest single operational period of the demonstration and the longest operational period with the full complement of sensors and the data logging system in place. The longest downtime during this period was 24 hours from 1600 on December 29, 1998, to 1600 on December 30, 1998. This intensively monitored operating period provided information to support evaluation of the system not only during this period, but also during operation earlier in the year. Plots of data recorded during this period are included in Volume I, Appendix A. The data set recorded includes the following parameters: blower pressure, blower temperature, blower status (on/off), pH in the NoVOCs™ well, and well recharge height.

In addition to the recorded parameters above, a tide prediction algorithm for tidal flux at the Navy Weapons Pier (the nearest shore point to the demonstration site) was developed, and the predicted tidal cycle was added to the recorded data plots. However, the data file for one 24-hour period during this operation (from about 0830 December 21 to 0830 December 22, 1998) was lost. Some significant observations derived from the operational data are discussed below.

C All of the parameters measured displayed some type of cyclical behavior. These cycles are largely attributed to either tidal cycle effects or diurnal temperature cycle effects. The blower temperature and blower pressure show strong correlation to diurnal temperature (blower temperature is highest in early afternoon). Blower pressure displayed a secondary effect of diurnal temperature. During early operation, Bechtel staff and subcontractors observed that water accumulated in the NoVOCs™ return air moisture separator during the cool periods of the night and evaporated from the separator during the heat of the day. This is consistent with condensation of water vapor from the saturated return air stream. During December, when the diurnal temperature range was more extreme, the collection of condensate reached the switch level in the separator and activated the ejector pump, which pumped the contents of the moisture separator into the supply airline. During this action, the water added to the supply air was observed to substantially increase the supply air pressure. Subcontractor staff confirmed this effect by direct observation during pumpout events.

The differential pressure output from the orifice plate flow sensor was monitored from December 31, 1998, through January 4, 1999, using an independent transducer and data logger. A plot of the indicated pumping rate for that period is shown in Figure 26. Review of the data indicate a strong cyclical pattern; however, correlation of the indicated



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 26
NoVOCs™ WELL PUMPING RATE
December 31, 1998 through January 4, 1999

Tetra Tech EM Inc.

pumping rate cycles to either tidal fluctuations or diurnal temperature has not been confirmed.

As expected, recharge water levels displayed tidal cycles superimposed on the water level. The pH level also displayed cyclical behavior that appears to correlate to the tidal cycle. One possible explanation for this cycle could be related to variations in the actual well pumping rate caused by tidal changes in the static water level. With an airlift pump, the pumping rate is directly proportional to the airline submergence (the depth of the air injection point below the static water level). The observed tidal flux in groundwater elevation at the NoVOCs™ demonstration site was a maximum of 0.5 feet. This variation in effective submergence could be expected to cause fluctuation in the pumping rate in cycle with the tide (as the tide rises, submergence increases, and pumping rate increases). An increasing pumping rate would cause dilution of the pH amendment chemical and a resulting slight increase in the observed pH. As the tide falls, the pumping rate would decrease slightly, and the pH would be expected to decrease slightly.

C The recharge water level displayed an increasing trend over time. This trend did not correlate to the observed tidal fluctuation and eventually resulted in a high-level shutdown of the system on December 29, 1998. This condition was diagnosed as resulting from biofouling of the recharge screen as discussed below.

C Control of fouling of the NoVOCs™ well. The NoVOCs™ demonstration well at Site 9 had been plagued by chemical and biological fouling since early in the demonstration. Based on observations of conditions in the well, fouling was diagnosed in three phases. Early in the operation (in April 1998), precipitation of hydrated ferric hydroxide ("iron fouling") was identified as a problem. The down-hole camera survey conducted in July 1998 also confirmed the presence of biofouling organisms in the well intake (lower) screen. It is likely that biofouling was also present in the recharge (upper) screen; however, because the recharge screen was wiped clean during removal of the internal well components, indications of biofouling were not observed during the video tape survey. MACTEC implemented measures in September 1998 to control both biofouling and iron fouling. Biofouling of the recharge screen was confirmed in December 1998. The initial attempt to control iron fouling through adding a commercial surfactant product was unsuccessful. Substantial accumulation of ferric hydroxide continued during operations in September and October 1998. A review of the manufacturer's recommended application rate versus the rate of surfactant actually applied revealed that the actual application of the product was substantially below the recommended rate during September and October. Similarly, the actual application of the commercial microbiocide to control biofouling may have varied from the manufacturer's recommendation. The microbiocide application frequency was programmed into the logic controller and was not user-adjustable. A lower-than-recommended rate of application may have contributed to the continued observed biofouling of the NoVOCs™ well.

Bechtel and subcontractors implemented citric acid addition in December 1998, which was shown to be very effective at controlling iron precipitation in the NoVOCs™ well. The citric acid was prepared by dissolving crystalline citric acid in water to make up a solution of approximately 20 percent citric acid. This solution was metered into the well at a constant rate during operation to maintain a pH level between 4 and 6. When the high-level shutdown of the NoVOCs™ system on December 29, 1998, was evaluated, the water within the well at both the inlet and recharge zones was found be clear (turbidity 1.5 to 2.5 NTU) and all iron was in solution (that is total and dissolved iron were equal concentrations). A summary of the iron concentration, pH, dissolved oxygen, and turbidity data observed in three zones of the well on December 30, 1998, is shown in Table 5.

Because the restart schedule did not permit disassembly of the well for diagnosis, the NoVOCs™ well outlet screen was evaluated for fouling by lowering a weighted tube into the well annulus and pumping continuous water samples from the annulus with a peristaltic pump. This approach revealed the accumulation of substantial quantities of filamentous microbial colonies across the full length of the recharge screen. These colonies were visually similar to the colonies observed in the inlet screen during the down-hole camera survey in July. This biofouling was the apparent cause of the high-level conditions in the NoVOCs™ well during the December time period. The apparent inability of the biocide injected into the intake screen zone to control fouling of the recharge screen may be related to one, or all, of three conditions: (1) the rate of addition of the biocide was insufficient to control the microbes in the well; (2) the biocide, or some active ingredient, may have been removed during the in-well stripping process, thus providing no active ingredient to the outlet screen; and (3) the biocide may have been somehow inactivated by the in-well stripping process or other conditions in the well.

To facilitate the timely restart of the system, Bechtel and subcontractors made an aggressive treatment of the recharge screen using the available biocide solution and hydrogen peroxide solution. The treatment solutions were placed in the recharge screen zone using the weighted tube and peristaltic pump that were used to diagnose the problem. Five gallons of biocide solution were placed in the recharge zone and left undisturbed for several hours. This was followed by placement of 5 gallons of 3 percent hydrogen peroxide solution and 4 gallons of 35 percent hydrogen peroxide solution to disrupt the microbial colonies. This treatment proved effective and the system was restarted on December 30, 1998, within the required 24-hour restart period. The controller programming could not be changed to increase the microbiocide injection frequency. However, the apparent water level within the well continued to rise, and subsequent high- level shutdowns were encountered on January 3 and 4, 1999. These shutdowns were accompanied by stable and declining water levels in the recharge piezometer, which suggests that biofouling of the recharge screen was the likely cause of the shutdowns.

The discovery of microbial colonies in the recharge screen in December suggests the possibility that the NoVOCs™ well had suffered biofouling in addition to iron fouling during early operations in May and June 1998. The presence of microbial colonies on the inlet screen in July, prior to implementation of any chemical amendments other than pH adjustment, indicated the possibility of biofouling of the upper (recharge) screen as well. During the earlier evaluation of the well, the eductor pipe was removed. This was done before development in May 1998 and before the down-hole camera survey in July 1998.

TABLE 5

RESULTS OF FIELD ANALYSES — DECEMBER 30, 1998
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Analysis	Well Inlet Zone	Well Recharge Zone	Recharge Piezometer
Dissolved Iron (mg/L)*	5	4	10
Total Iron (mg/L)*	5	4	10
pH (units)	4.5	4.5	4.2
Dissolved Oxygen (mg/L)	4	5	2
Turbidity (NTU)	2.5	1.5	120 66 (after 5 minutes)

Notes:

mg/L Milligram per liter
NTU Nephelometric turbidity units
* Iron analysis by colorimetric determination using CHEMets™ test kit.

The shale trap packer attached to the eductor pipe would be expected to wipe the inside surface of the recharge screen clean as the eductor is removed. This is likely the reason that the recharge screen appeared to be free of biofouling during the camera survey.

3.1.3 System Operation and Maintenance

The NoVOCs™ system required extensive maintenance during the demonstration. As shown in Volume I, Appendix A, Table A1, during the demonstration the NoVOCs™ system was down about 33 percent of the time. Operation and maintenance problems causing shutdown of the NoVOCs™ system were primarily related to (1) well fouling, (2) pH problems in the NoVOCs™ well, and (3) maintenance problems with the Thermatrix system. Additional periods of inactivity were associated with system design changes. A summary of the operation and maintenance problems is provided in Volume I, Appendix A, Table A2.

Well Fouling and Fouling Control. Well fouling can be the cause of substantial maintenance effort with any groundwater treatment system. The NoVOCs™ demonstration well at NAS North Island required substantial maintenance effort to manage fouling by microbial colonization (biofouling) as well as direct chemical precipitation of ferric hydroxide. In-well stripping systems and recirculating wells, such as the NoVOCs™ system, are subject to fouling from a variety of common causes, like any other production well and like many aboveground treatment technologies. The three most common causes of fouling in production wells are (1) accumulation of silt in the well structure, (2) formation of chemical precipitates and insoluble mineral species, and (3) biofouling by colonizing microorganisms. These issues and their relationship to the NoVOCs™ demonstration well are discussed below.

Fouling of recirculating wells is a recognized problem that requires diagnosis, design considerations, and operation and maintenance activities for successful management. Fouling can cause system failure due to reduced screen capacity in recirculating wells. Fouling can also extend into the filter pack and formation outside of the well.

Initial fouling control efforts at the NoVOCs™ demonstration well were approached systematically. Silt accumulation were to be controlled through design and construction of filter pack and well screen combinations that were appropriately sized for the formation sands at the site and by thorough development of the well prior to startup. Calcite scaling was to be managed through pH control based on the results of bench testing using samples of groundwater from the site during the detailed design phase (see Figures 16 and 17). The preliminary information available during system design indicated relatively low dissolved iron concentrations in groundwater (less than 0.1 mg/L) so iron precipitation control was not included in the initial design. Biofouling was not specifically assessed during system design.

<u>Siltation Effects.</u> The NoVOCs™ well exhibited minor fouling by silt and fine sand during the demonstration. A small quantity of fine sand (a volume of about one gallon) was removed from the well foot during inspection and redevelopment in May 1998. The water produced from the well exhibited very low turbidity (less than 5 NTU) following development. No significant quantities of formational silt or sand were deposited atop the shale trap packer on the eductor pipe after operation, also indicating thorough development and proper function of the screens and filter packs.

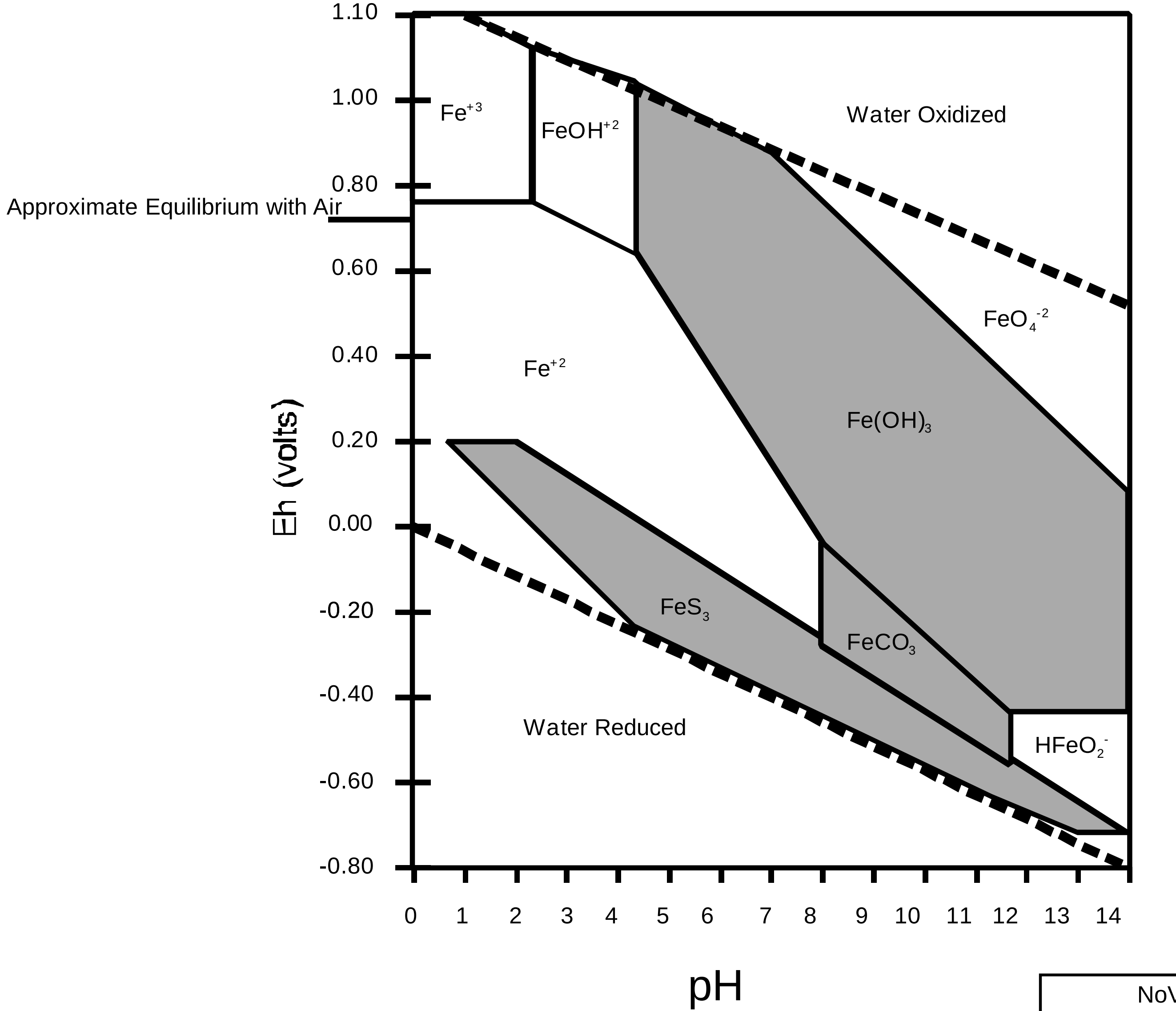
<u>Iron Fouling</u>. The NoVOCs™ demonstration well began to display substantial accumulation of flocculated hydrated ferric hydroxide within a few weeks of startup. The dissolved iron content of the groundwater in the NoVOCs™ well was also observed to be higher, ranging up to 4 mg/L after a period of operation. The precipitated iron is believed to have played a major role in fouling the recharge screen in

May and June 1998 with resultant high water level shutdowns of the NoVOCs™ system. The formation of insoluble ferric hydroxide by direct aeration of water containing dissolved ferrous iron is a predictable process. As water containing dissolved ferrous iron (Fe^{+2}) is aerated, the ferrous iron is oxidized to trivalent ferric iron, forming hydrated ferric hydroxide molecules. Hydrous ferric hydroxide polymerizes to form macroscopic particles, which can bridge screen slots and settle in quiescent areas to cause fouling problems. An iron speciation diagram is shown in Figure 27.

The solubility of iron in water is highly dependent on both the pH of the water and the oxidation/reduction (redox) potential (Eh). As shown in Figure 27, at near-neutral pH, iron can exist as either a soluble ion (divalent ferrous iron, Fe^{+2}), or one of two insoluble species (pyrite [FeS_2], a common species in reduced saline waters, or ferric hydroxide, [$Fe(OH)_3$]) depending on the redox potential. It is important to note that increasing the redox potential at this near-neutral pH range can result in an initial increase in ferrous iron from dissolution of pyrite minerals, with subsequent precipitation of ferric hydroxide as the redox potential approaches equilibrium with air. A detailed assessment of reduced iron mineralogy was not conducted during this NoVOCs™ demonstration. The redox potential of the contaminated zone surrounding the NoVOCs™ well inlet, however, was measured during aquifer testing and found to be slightly negative (i.e., -0.03 volt).

The in-well stripping action of the NoVOCs™ process tends to drive the redox potential toward equilibrium with air (approximately 0.75 volts) (see Figure 27). At the pH typically encountered in natural groundwater (pH 5.0 to pH 8.5) this will result in the formation of ferric hydroxide. The degree of precipitation of ferric hydroxide after aeration was determined in bench tests conducted by Bechtel subcontractors in June 1998. Dissolved iron concentration in a sample of groundwater from the NoVOCs™ demonstration site was 2.2 mg/L. After aeration, visible ferric hydroxide flocs settled in the beaker and the dissolved iron concentration decreased to 0.41 mg/L, corresponding to precipitation of 81 percent of the dissolved iron as ferric hydroxide (see Figure 27).

The internal components of the NoVOCs™ well were observed to be covered with a thick layer of gelatinous hydrous ferric hydroxide when removed from the well in May, June, and July, 1998. This gelatinous material rapidly dehydrates on exposure to air, leaving a thin layer of powdery orange ferric oxide. Depending on the degree of hydration and polymerization, ferric hydroxide deposits will exhibit a

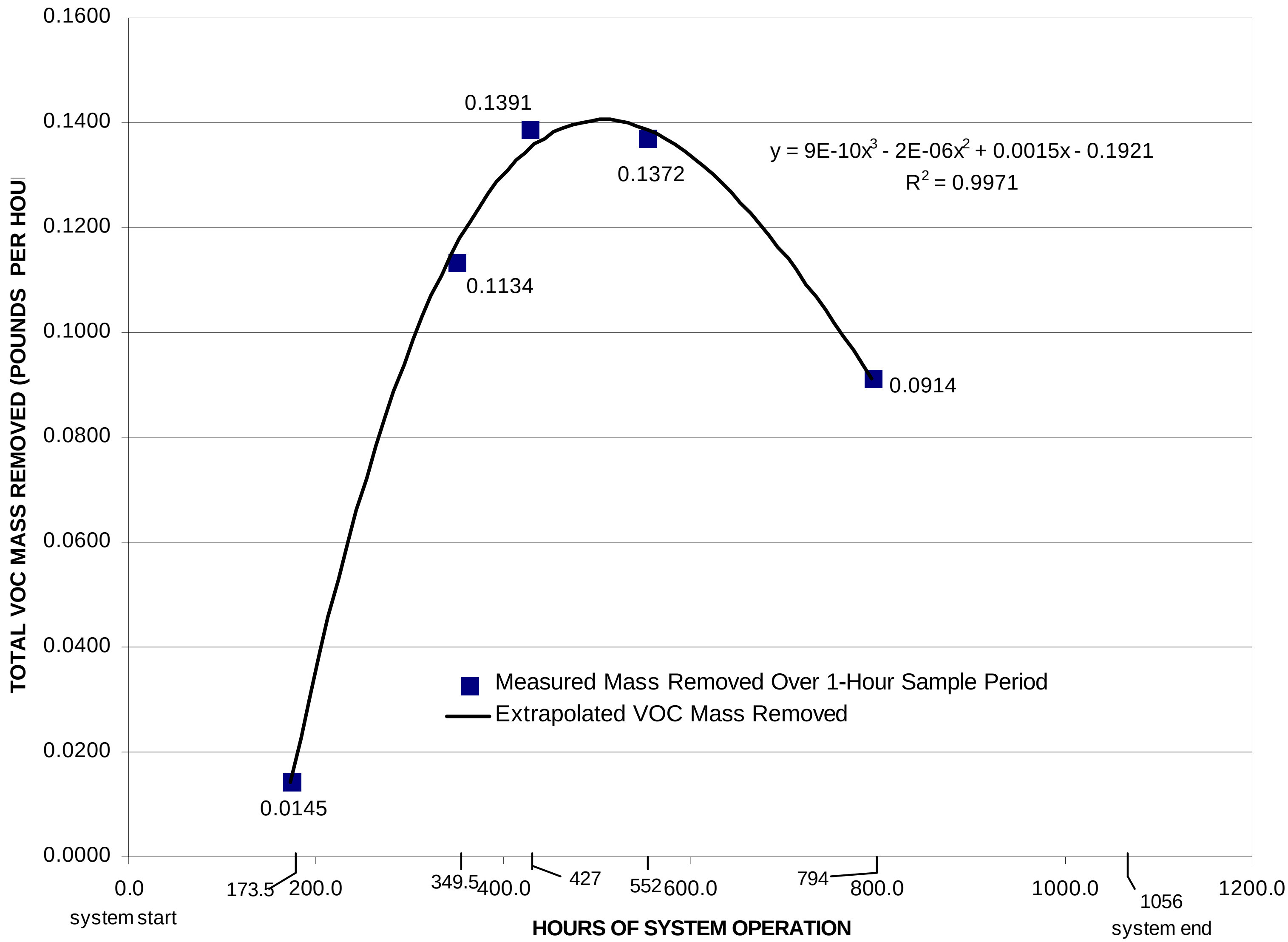


(modified from Hackett and Lehr, USACOE, 1985)

NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 27
SIMPLIFIED IRON STABILITY DIAGRAM

Tetra Tech EM Inc.



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 28
TOTAL VOC MASS REMOVED
BEST FIT TREND LINE

Tetra Tech EM Inc.

volume reduction of 300 to 600 percent when exposed to dry air. The accumulation of ferric hydroxide deposits has been observed previously in other NoVOCs™ installations and has been associated with other in-well stripping systems.

Ferric hydroxide deposits are also produced as a metabolic by-product by iron oxidizing bacteria, a group of numerous genera of common terrestrial and aquatic bacteria that derive energy from the oxidation of ferrous iron to ferric iron. Based on observation of the volume and placement of ferric hydroxide flocs during the down-hole camera survey of the NoVOCs™ demonstration well, most of the iron fouling appears to have been caused by direct oxidation of ferrous iron, with a potential for a smaller amount produced by iron-related bacteria located in the well inlet screen zone. Ferric hydroxide produced by microbial oxidation is generally indistinguishable chemically from that produced by direct oxidation by air.

The commercial product selected by MACTEC for control of ferric hydroxide precipitation was found to be ineffective at the rate and manner in which it was applied. The NoVOCs™ well exhibited continued accumulation of ferric hydroxide after the reconfigured system was started and operated in September and October. In December, Bechtel replaced the commercial surfactant product with a citric acid solution, which provided satisfactory control of ferric hydroxide precipitation. The effect of these iron precipitation control products (citric acid and the commercial dispersant) as a carbon source for microbes in the well was not evaluated.

<u>Biological Fouling</u>. Biological fouling of the NoVOCs™ demonstration well was first confirmed during the down-hole camera survey in July by observation of microbial colonies in the inlet screen. These colonies appeared generally as white to hyaline tufts of microbial mat attached to numerous inlet screen slots and partially blocked the inlet screen. Some distinct colonies exhibited orange coloration consistent with that of ferric hydroxide, suggesting that at least some of the colonies were iron-oxidizing bacteria. The outlet screen of the NoVOCs™ well was observed to be clear of biofouling during the camera survey; however, removal of the eductor pipe with its attached shale trap packer would have scraped microbial deposits from the outlet screen before the camera survey. In retrospect, it appears likely that the same degree of biological fouling observed in the inlet screen was also present in the outlet screen, but was not actually observed until later in the demonstration (December 1998). This biofouling of the outlet screen likely contributed to the reduced recharge capacity observed in May and June 1998, as well as later in the demonstration, as discussed below.

Bechtel staff collected a sample of the water removed from the well during development activities in July 1998 for a microbial screening analysis for iron-related bacteria, sulfur-related bacteria, and slime-forming bacteria. The results of this screening are summarized below. Bacterial populations were rated on a scale of 0 (absent) to 10 (high).

- The iron-related bacteria reaction showed iron bacteria growing, at least in part, in anaerobic conditions or at the redox front. There may well be significant populations of enteric bacteria with species of either Klebsiella and/or Enterobacter dominating. The population of bacteria was measured at 7.

- The first sulfur-reducing bacteria (SRB) showed bacteria growing covertly within slimes composed of a variety of slime-forming bacteria. The second reaction showed SRB bacteria growing within loose forms of slime in association with aerobic bacteria. The third reaction showed a diverse SRB community which was, in part, functioning with other aerobic and anaerobic bacteria. The population of SRBs were measured at 3.8.

- The first slime bacteria reaction showed a complex community of aerobic bacteria, many of which are able to grow on the redox front. The second reaction showed aerobic or anaerobic bacteria able to form gel-like slimes that may be easily disrupted. The third reaction showed that bacterial fouling was occurring involving a mixture of enteric and pseudomonad bacteria. The population was measured at 3.3.

These results suggested that bacteria pose a moderate to high risk for clogging, a low to high risk for corrosion, and were moderately to extremely aggressive. To address this problem, MACTEC collected groundwater samples from the NoVOCs™ well to determine the best approach to minimize iron precipitation and biofouling of the well. Based on the analysis of the groundwater sample, MACTEC modified the chemicals being injected in the well to include a modified hydroxylate copolymer to control scaling in the well and a bromine/chlorine biocide solution to control biofouling of the well, as discussed in Section 3.1.2. Injection of the modified chemical treatment began in September 1998 during operation of the NoVOCs™ system under redesigned operating conditions.

The selected treatment for biofouling of the NoVOCs™ well was a commercial microbiocide, a highly-oxidizing bromine/chlorine donor. This product was injected by a metering pump into the intake piezometer located in the filter pack outside of the inlet screen at the bottom of the well. This product did not appear to be effective as applied to the NoVOCs™ well. After restarting the system in December 1998, a high water level condition was observed in late December (see operations discussion in Section 3.1.2). Diagnosis of the condition revealed substantial microbial growth fouling the recharge screen of the

NoVOCs™ well. Bechtel submitted a sample of water containing this material for microbial screening. The results of the screening (with relative populations reported on a scale of 0 to 10) are summarized below.

- Three types of slime-forming bacteria were identified with a relative population of 7, a moderate clogging risk. These microbes were described as being extremely aggressive.

- Highly-aggressive SRB were present within the slimes. These microbes present a moderate clogging risk and were present in a relative population of 2.4.

- Extremely aggressive iron-related bacteria and populations of enteric and pseudomonad bacteria were present at relative populations of 7. These bacteria present a high clogging risk.

The consortium of microbes identified in the recharge screen in December is very similar to that identified in July in the well inlet screen. A photograph of specimens of the organisms sampled in December is shown in Figure 19d. The reasons for ineffective results from the microbiocide applications are not readily apparent.

System pH. Airlift pumping used by the NoVOCs™ system introduces oxygen into the treated groundwater. Introduction of oxygen results in higher oxidizing conditions in the groundwater, which will tend to precipitate redox sensitive elements such as iron and manganese. Additionally, elevated concentrations of aqueous iron support the growth and proliferation of iron-related bacteria. The precipitation of an inorganic such as iron and associated bacterial growth can potentially plug the well screen or the surrounding aquifer or reduce the hydraulic conductivity of the formation. Airlift pumping also causes the removal of CO_2 from the treated groundwater. For carbonate-rich groundwater, stripping of CO_2 causes an increase in pH in the treated groundwater and the subsequent precipitation of calcium minerals (calcite), which may adversely impact the ability of well screens, the filter pack, and the adjacent formation to transmit water.

To address these potential problems, HCl was injected into the water treated by the NoVOCs™ system using an automatic pH control system. Initial pH injection settings were determined by conducting sparge and titration tests on groundwater from the demonstration site. Based on the results of the sparge and titration tests, approximately 0.25 milliliters (ml) of 30 percent HCl solution per liter of treated water was required to return the pH to a point near the initial pH of 7.40 to 7.80. During operation of the NoVOCs™ system, several problems with the pH control system were encountered. On one occasion, the pH electrode was shorted by water leaking into the electrode support pipe. The pH signal pre-amplifier batteries proved to have relatively short service lives and required replacement on an irregular basis. As the NoVOCs™ well began to display reduced recharge capacity, pH control began to display off-normal conditions due to the reduced well pumping rate. The acid addition system, while correctly sized for the design flows, was oversized for the reduced rates encountered during periods of fouling of the recharge screen.

Thermatrix System. Because the NoVOCs™ and Thermatrix systems were interconnected, problems with one system would cause the other system to go off line. On several occasions, the NoVOCs™ system was shut down because of maintenance problems with the Thermatrix system. For the most part, the Thermatrix system operated with few problems until September 1998. During the redesigned operational period, the Thermatrix system began experiencing maintenance problems, including high pH levels, low quench levels, and clogged injection jets. Most of these problems appeared to be related to the Thermatrix system not being operated for more than 3 months.

3.1.4 Colloidal Borescope

In October 1997, the Navy measured groundwater direction and velocity in five wells at Site 9 using an innovative in situ field measurement device, known as the colloidal borescope. The colloidal borescope provides direct means of accurately determining groundwater flow direction in a well by measuring the movement of natural particles in the groundwater within the well. The colloidal borescope was developed by Oak Ridge National Laboratory's (ORNL) Environmental Technology Section and consisted of a set of lenses and miniature video cameras capable of observing natural particles in monitoring wells. Based on field observations of these particles, in situ groundwater velocity and flow direction in a well can be measured.

The colloidal borescope consists of two charge-couple device (CCD) cameras, a ball compass, an optical magnification lens, an illumination source, and stainless-steel housing. Upon insertion into a well, an electronic image magnified 140 times is transmitted to the surface, where it is viewed and analyzed. The compass is viewed by one of the CCD cameras to align the borescope in the well. As particles pass beneath the lens, the back-lighting source illuminates the particle (similar to a conventional microscope with a lighted stage). A video frame grabber digitizes individual video frames at intervals selected by the operator. The software compares the two digitized video frames, matches particles from the two images, and assigns pixel addresses to the particles. Using this information, the software program computes and records the average particle size, number of particles, speed, and direction. A computer can analyze flow measurements every 4 seconds, resulting in a large database after only a few minutes of observations.

Of the five wells measured at Site 9, a reliable flow rate was recorded in one of the five wells, well S9-DMW-1, at a depth of 61.8 feet below casing level, while the remaining flow rates taken at various intervals in the other test wells did not yield a reliable flow measurement. ORNL believes that several factors were responsible for this unreliability in measurements (for example, vertical flow and clogged well screens), and that with some equipment modifications and redevelopment of the existing wells, it would be possible to obtain reliable flow measurements using the colloidal borescope.

Over 5 hours of data were collected from monitoring well S9-DMW-1. The data indicated that groundwater flows in a west-southwest direction at an average corrected velocity of 5 ft/day. This velocity measurement is for a preferential flow zone and has been reduced the maximum amount to take into account the effects of the borehole. Based on groundwater elevation data collected by Bechtel, this flow direction is consistent with site data that suggests a southern component in a generally western groundwater flow direction.

Because of the limited results of the earlier colloidal borescope investigation, shoreline monitoring wells 9-MW-18 and 9-MW-26 were selected and tested using the colloidal borescope instrument in March 1998. Both wells showed a west-southwest flow direction that was consistent with earlier observations.

3.1.5 Diffusion Multi-Layer Sampler

In May 1998, the Navy conducted field sampling of monitoring well MW-54 using a Diffusion Multi-Layer Sampler (DMLS™) to evaluate the vertical distribution of contaminant in the groundwater in the vicinity of the NoVOCs system. The DMLS™ is a passive, multi-layer sampling device that consists of a series of connected rods with openings at specific intervals to accommodate proprietary dialysis cells. The dialysis cells consist of a polypropylene vial filled with distilled water, which are covered by permeable membranes at both ends. Each cell is an independent sampling unit, separated by flexible seals that fit the inner diameter of the well. When a dialysis cell is exposed to groundwater with concentrations of solutes different from that inside the cell, a natural process of diffusion of solutes from higher concentrations to lower concentrations occurs.

A 35-foot-long DMLS™ with dialysis cells spaced approximately every 2 feet was installed in monitoring well MW-54 on May 6, 1998. The dialysis cells were allowed to equilibrate with the surrounding groundwater for a period of 7 days. On May 13, 1998, the DMLS™ was removed and a total of 18 discrete dialysis cells were collected for subsequent analysis at an analytical laboratory.

Analytical results from the sampled collected using the DMLS™ provided a detailed vertical profile of the contaminant concentrations at Site 9. The primary VOCs detected were PCE, TCE, 1,1-DCE, 1,2-DCE, and vinyl chloride. Based on a review of the contaminant concentrations, the distribution of these contaminants appeared to be stratified. Elevated levels of total VOCs were detected in the four samples collected from 45 to 50.2 feet bgs. Total VOC concentrations in this zone exhibited a decreasing trend with depth from a high of 20,339 Fg/L at 45 feet bgs to a low of 6,018 Fg/L at 50.2 feet bgs. Lower concentrations of total VOCs were detected in the six samples collected from 52.3 to 62.6 feet bgs. Total VOCs in this zone ranged from 807 to 3,778 Fg/L and exhibited no apparent trends. The highest concentrations of total VOCs were detected in eight samples collected from 64.7 to 79 feet bgs. These samples exhibited a trend of increasing total VOC concentrations with depth from a low of 54,613 Fg/L at 64.7 feet bgs to a high of 98,028 Fg/L at 79 feet bgs. A summary of the DMLS™ analytical results is present in Volume I, Appendix A, Table A-36.

Based on discussions with Bechtel and review of the borehole log from the NoVOCs well, the observed contaminant stratification may be related to site stratigraphy. A correlation appears to exist in the sudden and marked increase in total VOC concentrations observed in samples collected at 62.5 feet and below and the dense sand layer encountered at about 61 feet bgs.

3.2 RESULTS

This section presents the results of the SITE evaluation of the NoVOCs™ technology at NAS North Island, California. The results are presented by project objective and have been interpreted in relation to each objective. The specific primary and secondary objectives are shown at the top of each section in italics followed by a discussion of the objective-specific results. Data quality based on these results is presented in Section 3.3.3.

3.2.1 Primary Objectives

Primary objectives were considered to be critical for the evaluation of the NoVOCs™ technology. Three primary objectives were selected for the SITE evaluation of the NoVOCs™ technology. The results for each primary objective are discussed in the following subsections.

3.2.1.1 Primary Objective P1

Evaluate the removal efficiency of the NoVOCs™ well system for VOCs in groundwater.

This objective was achieved by collecting groundwater samples from piezometers adjacent to the system intake (PZ-02) and recharge (PZ-01) and analyzing the samples for VOCs. Because the NoVOCs™ system did not operate continuously over the anticipated demonstration period, groundwater samples were only collected during the first, second, and third weekly, and first monthly sampling events. In addition to VOC data collected during the SITE evaluation, VOC data collected by Bechtel were also documented. The analytical results for VOCs detected in the system intake (PZ-02) and recharge (PZ-01) piezometers for both the Tetra Tech and Bechtel sampling events are summarized in Table 6. While the initial objective included calculating a removal efficiency for PCE, TCE, DCE, vinyl chloride, and BTEX, only three VOCs were consistently detected at measurable concentrations during the system demonstration: 1,1-DCE, cis-1,2-DCE, and TCE. As such, removal efficiencies were only calculated for these three compounds.

The results indicate that the NoVOCs™ system effectively removed these target compounds from the groundwater. 1,1-DCE was reduced by greater than 98 percent in all events except the first Bechtel sampling event on February 6, 1998. Cis-1,2-DCE was reduced by greater than 95 percent in all sampling events, except the first Bechtel sampling event. TCE was reduced by greater than 93 percent in all the sampling events except the first Bechtel sampling event. Removal efficiencies calculated during the first Bechtel sampling event for 1,1-DCE, cis-1,2-DCE, and TCE were 90, 48, and 76 percent,

TABLE 6

TREATMENT SYSTEM REMOVAL SUMMARY
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Well	Description	Sampling Event								
		Bechtel 3/4/98	**Bechtel 3/19/98**	**Tetra Tech 1st Weekly 4/28/98**	**Bechtel 4/29/98**	**Tetra Tech 2nd Weekly 5/6/98**	**Tetra Tech 3rd Weekly 5/12/98**	**Tetra Tech 4th Weekly 5/21/98***	**Tetra Tech 1st Monthly 6/8/98**	**Bechtel 6/8/98**
1,1-Dichloroethene (Fg/L)										
PZ-02	System Intake	**2,700**	**2,800**	**2,300**	**4,400**	**2,400**	**3,100**	NA	**4,300**	**5,400**
PZ-01	System Recharge	**270**	**50**	**25**	**30**	**16**	**26**	NA	**9.3**	**34**
Percent Reduction [(1)]		90	98	99	99	99	99	NC	99	99
cis-1,2-Dichloroethene (Fg/L)										
PZ-02	System Intake	**13,000**	**40,000**	**45,000**	**52,000**	**39,000**	**40,000**	NA	**46,000**	**53,000**
PZ-01	System Recharge	**6,700**	**2,100**	**1,800**	**1,500**	**1,200**	**1,500**	NA	**580**	**1,100**
Percent Reduction [(1)]		48	95	96	97	97	96	NC	99	98

TABLE 6 (Continued)

TREATMENT SYSTEM REMOVAL SUMMARY
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Well	Description	Sampling Event								
		Bechtel 3/4/98	**Bechtel 3/19/98**	**Tetra Tech 1st Weekly 4/28/98**	**Bechtel 4/29/98**	**Tetra Tech 2nd Weekly 5/6/98**	**Tetra Tech 3rd Weekly 5/12/98**	**Tetra Tech 4th Weekly 5/21/98***	**Tetra Tech 1st Monthly 6/8/98**	**Bechtel 6/8/98**
Trichloroethene (Fg/L)										
PZ-02	System Intake	**790**	**1,300**	**760**	**1,600**	**1,900**	**2,000**	NA	**2,300**	**1,700**
PZ-01	System Recharge	**190**	**65**	**50**	**25**	**26**	**27**	NA	**9.2**	**18**
Percent Reduction [(1)]		76	95	93	98	99	99	NC	99	99

Notes:
Fg/L Micrograms per liter
NA Not analyzed
NC Not calculated
* Groundwater samples were not collected from PZ-01 and PZ-02 during the fourth weekly sampling event.
[(1)] Percent reduction = $[[C_{(W-1)} - C_{(W-2)}] / C_{(W-1)}] \times 100$; where $C_{(W-1)}$ = PZ-02 and $C_{(W-2)}$ = PZ-01
Bolded values are above the reporting limit

respectively. The lower removal efficiencies calculated during this sampling event are believed to be related to the fact that the sampling event was conducted during system shakedown activities. A summary of the removal efficiencies are provided in Table 6.

The upper confidence limit (UCL) for 1,1-DCE, cis-1,2-DCE, and TCE in the samples of the treated groundwater was determined at the 95 percent confidence level using a one-tailed Student's t-test. For the UCL, data from all the sampling events, except the first Bechtel sampling event were used. The UCL for each of these three VOCs was calculated using the following equation:

$$UCL_{t,95\%} = x + \frac{ts}{\sqrt{n}}$$

Where:

x	=	Sample mean contaminant concentration
t	=	Student's t-test statistic value at the 95 percent confidence level
s	=	Sample standard deviation
n	=	Sample size (number of measurements)

The following parameters were calculated from the 1,1-DCE, cis-1,2-DCE, and TCE concentration data presented in Table 6.

1,1-DCE	cis-1,2-DCE	TCE
x = 27.19	x = 1,397	x = 31.45
t = 1.943	t = 1.943	t = 1.943
s = 13.09	s = 495	s = 19.31
n = 7	n = 7	n = 7

Given the parameters above, the UCLs at the 95 percent confidence level for 1,1-DCE, cis-1,2-DCE, and TCE in the treated effluent are:

1,1-DCE	cis-1,2-DCE	TCE
37 µg/L	1,760 µg/L	46 µg/L

The MCLs for 1,1-DCE, cis-1,2,-DCE, and TCE are 6 µg/L, 6 µg/L, and 5 µg/L, respectively. MACTEC claims that the NoVOCs™ system can reduce VOC concentrations in groundwater to below MCLs if the contaminant source has been removed. However, because DNAPLs may be present in the aquifer, MACTEC did not make any claims for reduction of dissolved VOC concentrations in the groundwater.

3.2.1.2 Primary Objective P2

Determine the radial extent of the NoVOCs™ treatment cell.

The original intent of this investigation was to evaluate the radial extent of the NoVOCs™ treatment cell by conducting a series of tracer dye tests. However, because of the sporadic operation of the NoVOCs™ system, the dye trace study was not conducted, and a direct evaluation of the radial extent of the NoVOCs™ treatment cell was not performed. In lieu of the dye trace study, the aquifer pump tests conducted to assess the hydrogeologic characteristics of the site were used to indirectly evaluate the radial extent of the NoVOCs™ treatment cell. Although the aquifer pump tests cannot be directly applied to evaluate the radial extent of the NoVOCs™ treatment cell or even that groundwater recirculation was established, the test data provides information on the radius of influence of the well under pumping (2-dimensional) and dipole (3-dimensional) flow conditions. The resulting changes in pressure head provide an indication of the potential for flow in the surrounding aquifer and are used to provide an estimate of the radial extent of influence created by the NoVOCs™ well. However, the pressure head changes do not accurately represent flow patterns or contaminant transport, and as such, no firm conclusions can be drawn about the radial extent of the NoVOCs™ treatment cell.

A constant discharge rate pumping test was conducted in the shallow aquifer zone to characterize aquifer hydraulic properties by pumping the recharge chamber of the NoVOCs™ well. The constant discharge pumping test data indicate that the shallow aquifer zone is fairly transmissive in the horizontal direction. The upper and lower aquifer zones are also well connected with the vertical hydraulic conductivity approximately one-fifth of the horizontal conductivity value (the anisotropy ratio, Kr/Kv is about 5). During the constant discharge rate (Q = 20 gpm) pumping test, measurable drawdowns (+/- 0.01 feet) were observed at about 100 feet from the NoVOCs™ well in all directions and at different depths. This information indicates that the radius of influence by extraction, specifically at 20 gpm, could be as large as 100 feet.

A dipole flow test, which mimics NoVOCs™ system operation, was conducted to further evaluate the aquifer anisotropy. The dipole flow test was conducted by pumping the lower chamber of the NoVOCs™

well and simultaneously injecting water into the upper chamber. The test was conducted using different extraction and injection rates at different step intervals. The maximum extraction-injection rate used during the test was about 24 gpm. Water level data collected at the 30-foot crossgradient well clusters showed a clear and identifiable rise (drawup) in the shallow zone monitoring well (MW-45) at each step of the test. Pressure responses at each test step were observed in MW-46 and MW-47, which were screened between the pump and injection chamber (MW-46) and lower aquifer zones (MW-47). No measurable drawdown or drawup could be identified in well MW-46. Drawdown in well MW-47 was also insignificant. The 60-foot crossgradient well cluster (MW-48 and MW-49) also showed pressure responses at the beginning of each step in the test. However, drawdowns or drawups were not identified in these wells. Pressure responses to the dipole flow test generally dissipated at 100 feet from the NoVOCs™ well. A small negative pressure pulse and a small positive pressure pulse were recorded in wells MW-52, MW-53, and MW-54 at the beginning and end of the dipole flow test.

In summary, the dipole flow test data shows that measurable pressure responses occur at crossgradient locations 30 feet from the NoVOCs™ well and may be observed at farther distances. However, no drawdowns or drawups were positively identified in monitoring wells beyond the 30-foot distance.

3.2.1.3 Primary Objective P3

Quantify the mass of total VOCs removed from groundwater treated by the NoVOCs™ system over the 6 month evaluation period.

Because of operational problems with the NoVOCs™ system, this objective was not evaluated for the entire 6 month period. The mass removal of VOCs was calculated for the period of April 28 through June 8, 1998, by measuring the air flow rate and concentration of VOCs in air entering and exiting the NoVOCs™ system. The NoVOCs™ system was operational approximately 70 percent of the time during this period, and pumping rates were estimated to range from 10 to 24 gpm. Total VOC concentrations were determined by collecting duplicate, 1-hour integrated air samples using Summa canisters equipped with flow meters from air sampling ports A1 (influent air) and A2 (effluent air) (see Figure 4), and analyzing the samples for VOCs using EPA Method TO-14. The average total VOC concentration of the two duplicate samples was used for each sampling event. Volumetric flow was measured using certified orifice plates installed adjacent to air sampling locations A1 and A2. Air flow rates were collected at the start, middle, and end of the 1-hour sampling period. The three measurements were averaged to calculate the average hourly flow rate for each sampling event. A total of five air samples and flow rate measurement events were conducted during the demonstration; once per week during the first month (4 events) and one monthly event. Additional samples were not collected because of system operational problems encountered during the demonstration. A summary of the VOCs detected and flow rate measurements collected from A1 and A2 are provided in Tables 7 and 8.

The mass of total VOCs removed during the 1-hour sample collection period was calculated by multiplying the average 1-hour flow rate times the concentration of total VOCs detected during the sampling event, using the following equation:

$$M_v = (Q_{va} \times C) \times \Delta t$$

Where:

M_v	=	Mass of total VOCs removed during each sampling event
Q_{va}	=	Average 1-hour volumetric air flow rate measured at the effluent air sampling port A2
C	=	Total VOC concentration as measured from the effluent air sampling port A2
Δt	=	Change in time (1-hour)

Because concentration data were reported in ppb v/v, the data were converted into mass per volume using the Ideal Gas Law, as summarized below:

(1) The Ideal Gas Law was used to calculate the gram moles of air per minute per sample:

$$n_i = \frac{PV_i}{RT}$$

Where:

n_i	=	Gram moles of air per minute for effluent sample collected during event i
P	=	Standard pressure of 1 atmosphere (760 millimeters of mercury)
V_i	=	Flow rate (standard cubic feet per minute) of air measured for effluent sample collected during event i
R	=	Ideal Gas Law: 2.2022
T	=	Standard temperature of 60 °F

TABLE 7

AIR SAMPLE RESULTS – NOVOCS™ INFLUENT SAMPLING PORT A1
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Chemical Parameters	Sampling Event				
	1st Weekly 4/28/98	**2nd Weekly 5/6/98**	**3rd Weekly 5/12/98**	**4th Weekly 5/21/98**	**1st Monthly 6/8/98**
Volatile Organic Compounds (ppb v/v)					
Benzene	<0.39	<0.44	<0.42	<0.54	<0.47
Chlorobenzene	<0.39	<0.44	<0.42	NA	<0.47
Chloroform	<0.39	<0.44	<0.42	<0.54	<0.47
Dichlorodifluoromethane	**0.56**	**0.52**	**0.57**	**0.63**	**0.60**
1,1-Dichloroethene	<0.39	<0.44	<0.42	<0.54	<0.47
Cis-1,2-Dichloroethene	<0.39	<0.44	<0.42	<0.54	<0.47
Tetrachloroethene	<0.39	<0.44	<0.42	<0.54	<0.47
Toluene	<0.39	**0.44**	<0.42	**1.1 B,N**	**0.57 B**
Trichloroethene	<0.39	<0.44	<0.42	<0.54	<0.47
1,1,2-Trichloro-1,2,2-trifluoroethane	<0.39	<0.44	<0.42	<0.54	<0.47
1,2,4-Trimethylbenzene	<0.39	<0.44	<0.42	**0.54**	<0.47
1,3,5-Trimethylbenzene	<0.39	<0.44	<0.42	<0.54	<0.47
m- and p-Xylenes	<0.39	<0.44	<0.42	<0.54	<0.47
Total VOCs	**0.56**	**0.96**	**0.57**	**1.17**	**1.17 B**
Physical Parameters					
Pressure in inches WC	NA	4.85	5.1	4.9	4.5
Flowrate in scfm	60*	69	71	70	67

Notes:
B Blank contamination, result may be biased high
N Data judged not usable because of indicated data quality problem
< Less than
NA Not analyzed
ppb v/v Parts per billion on a volume per volume basis
scfm Standard cubic feet per minute
VOC Volatile organic compound
WC Water column
* Air flow rate was measured at the NoVOCs™ trailer. All other physical parameters were measured at air sampling location A1
Bolded values are above the reporting limit

TABLE 8

AIR SAMPLE RESULTS – NOVOCS™ EFFLUENT SAMPLING PORT A2
NoVOCS™ SITE Demonstration
Site 9, NAS North Island, California

Chemical Parameters	Sampling Event				
	1st Weekly 4/28/98	**2nd Weekly 5/6/98**	**3rd Weekly 5/12/98**	**4th Weekly 5/21/98**	**1st Monthly 6/8/98**
Volatile Organic Compounds (ppb v/v)					
Benzene	<260	<1,200	<1,400	<1,300	<1,200
Chlorobenzene	<260	<1,200	<1,400	<1,300	<1,200
Chloroform	<260	<1,200	<1,400	<1,300	<1,200
Dichlorodifluoromethane	<260	<1,200	<1,400	<1,300	<1,200
1,1-Dichloroethene	**2,000**	**13,000**	**17,000**	**17,000**	**12,000**
cis-1,2-Dichloroethene	**12,000**	**84,000**	**100,000**	**110,000**	**76,000**
Tetrachloroethene	<260	<1,200	<1,400	<1,300	<1,200
Toluene	<260	<1,200	<1,400	<1,300	<1,200
Trichloroethene	**500**	**3,500**	**4,100**	**4,200**	**2,900**
1,1,2-Trichloro-1,2,2-trifluoroethane	**560**	**3,600**	**4,600**	**4,800**	**3,000**
1,2,4-Trimethylbenzene	<260	<1,200	<1,400	<1,300	<1,200
1,3,5-Trimethylbenzene	<260	<1,200	<1,400	<1,300	<1,200
m- and p-Xylenes	<260	<1,200	<1,400	<1,300	<1,200
Total VOCs	**15,060**	**104,100**	**125,700**	**136,000**	**93,900**
Physical Parameters					
Pressure in inches WC	NA	6.1	6.25	5.6	5.0
Flowrate in scfm	60*	68	69	63	61

Notes:
< Less than
NA Not analyzed
ppb v/v Parts per billion on a volume per volume basis
scfm Standard cubic feet per minute
VOC Volatile organic compound
WC Water column
* Air flow rate was measured at the NoVOCs™ trailer. All other physical parameters were measured at air sampling location A2.
Bolded values are above the reporting limit

(2) Gram moles of VOCs per minute were calculated using the value n_i calculated above as follows:

$$Gram\,moles\,VOCs\,per\,\min \,'\, \frac{C_i}{10^9}\,X\,n_i$$

Where:

C_i	=	Concentration in parts per billion on a volume per volume basis for effluent sample collected during event I
n_i	=	Gram moles of air per minute for effluent sample collected during event i

(3) Pounds of total VOCs per 1-hour event were calculated using the value for gram moles VOCs per minute calculated above as follows:

$$Total\,VOC\,Mass\,(lb)\,Per\,Hour \,'\, \frac{gram\,moles\,VOC\,per\,\min\,X\,MW_i}{453.59\,grams\,per\,pound}\,X\,\frac{60\,minutes}{1\,hour}$$

Where:

MW_i	=	Molecular weight of VOCs detected in effluent sample collected during event i

Because the concentration of total VOCs in the influent air stream was less than 1 percent of the concentration of total VOCs removed by the system, the mass of total VOCs from the influent air stream is considered to be negligible, and the average mass of total VOCs removed was calculated using the effluent sample results only. The results of the average mass removed during each 1-hour sampling event are summarized in Table 9. During the period from April 28 to June 8, 1998, the average total VOC mass removed by the NoVOCs™ system ranged from 0.01 to 0.14 lb/hr and averaged 0.10 lb/hr during the five sampling events.

A plot of the average mass of total VOCs removed during each sampling event verses time is presented as Figure 28. To determine the total VOC mass removed by the NoVOCs™ system during the period from April 28 through June 8, 1998, a best fit curve was applied to the plotted data and the area under the curve was calculated. Assuming that the 1-hour sampling events were representative of the operating conditions and contaminant concentrations during the period of April 28 through June 8, 1998, the total VOC mass removed was about 90 pounds. However, this method of determining mass overestimates the actual mass removed because it assumes continuous operation of the NoVOCs™ system during the sampling period. As documented in Section 3.1, the NoVOCs™ system only operated about 70 percent of the time or about 707 hours between April 28 through June 8, 1998.

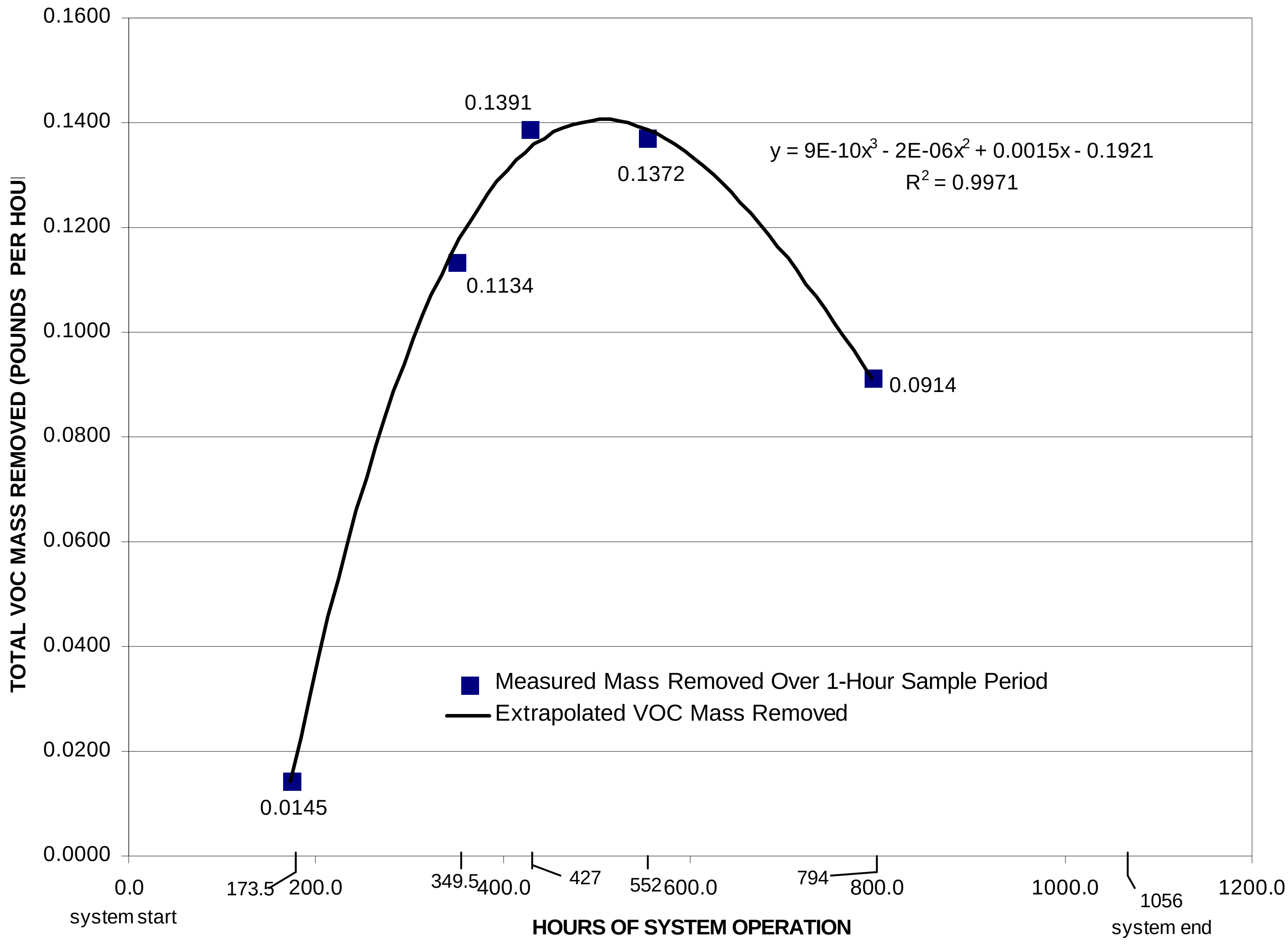
TABLE 9

SUMMARY OF THE TOTAL VOC MASS REMOVED
EFFLUENT AIR SAMPLING PORT A2
NOVOCS™ SITE Demonstration
Site 9, NAS North Island, California

Effluent Sampling Event (Date)	Effluent Total VOC Concentration Per Event (ppb v/v)	Effluent Air Flow Rate During Event (scfm)	Effluent Total VOC Mass Removed Over 1-Hour Sampling Event (lb/hr)**
1st Weekly (4/28/98)	15,060	60 *	0.01
2nd Weekly (5/6/98)	104,100	68	0.11
3rd Weekly (5/12/98)	125,700	69	0.14
4th Weekly (5/21/98)	136,000	63	0.14
1st Monthly (6/8/98)	93,900	61	0.09
Average	95,000	64.2	0.10

Notes:

*	Flow meter not installed at sample time; measurement obtained from NoVOCs™ trailer
**	Mass calculated using the Ideal Gas Law, assuming standard sample temperature (60 EF) and pressure (1 atmosphere)
ppb v/v	Parts per billion on a volume per volume basis
scfm	Standard cubic feet per minute
lb/hr	Pounds per hour
VOC	Volatile organic compound



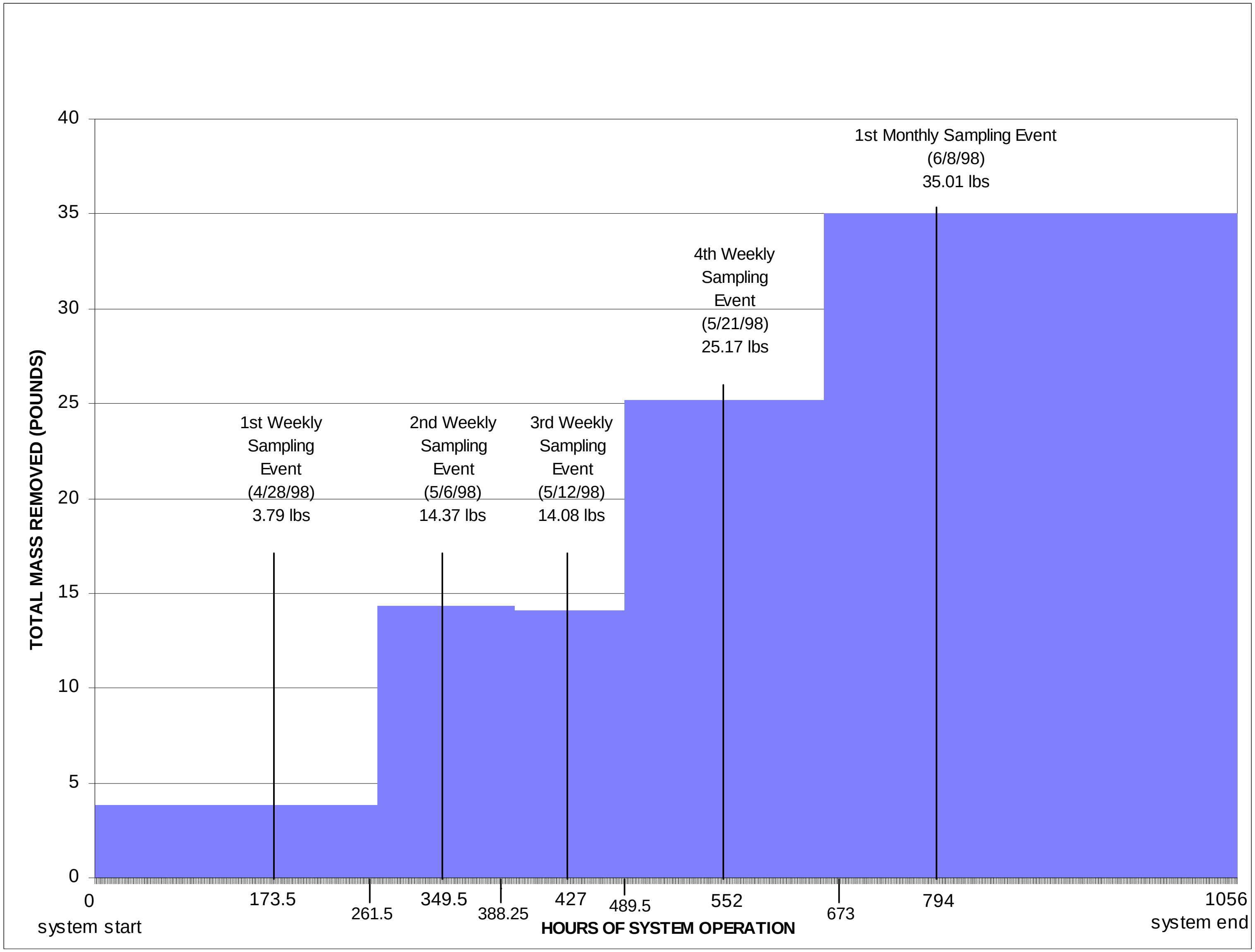
NoVOCs™ SITE Demonstration Site 9, NAS North Island, California
FIGURE 28 **TOTAL VOC MASS REMOVED** **BEST FIT TREND LINE**
Tetra Tech EM Inc.

To account for the sporadic operation of the NoVOCs™ system, the mass of total VOCs removed during the entire operation period from April 20 through June 19, 1998, was calculated by multiplying the average hourly total VOC mass removed during each sampling event times the operation period associated with that period. The mass of total VOCs removed during each of the five sampling events was subsequently summed to calculate the total mass removed during the 61-day operation period. For the total VOC mass removed during the first weekly sampling event, the operation period beginning at system startup on April 20, 1998, to the mid-operational time point between the first and second weekly sampling events was used. Subsequently, the period from the mid-operational time point between the first and second weekly sampling events and the second and third weekly sampling events was used to calculate the total VOC mass removed associated with the average hourly removal rate for the second sampling event. This same procedure was used to determine the operation periods associated with the third and fourth weekly average hourly removal rates. For the first monthly average hourly removal rate, the period beginning at the mid-operational time point between the fourth weekly sampling event and the first monthly sampling event and ending with the shutdown of the NoVOCs™ system on June 19, 1998, was used. A summary of the duration of the operating periods and amount of mass removed during each of the five sampling periods is presented in Figure 29.

Using the method described above, the mass of total VOCs removed during the period of April 20 through June 19, 1998, was calculated to be approximately 92.4 pounds. During this period, the NoVOCs™ system operated a total of 1,056 hours or about 72 percent of the time, and had an average mass removal rate of approximately 0.09 lb/hr or about 2.1 pounds per day of total VOCs.

3.2.2 Secondary Objectives

Secondary objectives provide additional information that is useful, but not critical, for the evaluation of the NoVOCs™ system. Seven secondary objectives were selected for the SITE evaluation of the NoVOCs™ system. The results of each secondary objective are discussed in the following subsections.



NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

FIGURE 29
TOTAL VOC MASS REMOVED DURING SYSTEM OPERATION

Tetra Tech EM Inc.

3.2.2.1 Secondary Objective S1

Quantify the changes in VOC concentrations in the groundwater within the NoVOCs™ treatment cell.

This objective was evaluated by collecting groundwater samples from piezometers PZ-01 and PZ-02 and monitoring wells MW-45 through MW-54 and analyzing the samples for VOCs. Because the NoVOCs™ system did not operate continuously over the anticipated demonstration period, groundwater samples were only collected during the baseline, first monthly, and second baseline sampling events. In addition to VOC data collected during the SITE evaluation, VOC data collected by Bechtel from the piezometer and monitoring wells were also documented. The analytical results reported by Bechtel and Tetra Tech for VOCs detected in PZ-01 and PZ-02 and monitoring wells MW-45 through MW-54 are summarized in Tables 10 through 12. Only three VOCs were consistently detected at measurable concentrations during the system demonstration: 1,1-DCE, cis-1,2-DCE, and TCE.

Based on the review of the analytical results, VOC concentrations appear to be stratified in the aquifer. In general, the highest concentrations of the three primary VOCs, 1,1-DCE, cis-1,2-DCE, and TCE were detected in the deep monitoring wells. This trend was especially pronounced for cis-1,2-DCE, which was detected at concentrations between 440 and 96,000 Fg/L in the deep wells, but only between 120 and 1,200 Fg/L in the shallow wells. The intermediate wells generally had the lowest concentration of all three primary VOCs. This pattern of contaminant stratification was confirmed with the data collected with the diffusion multi-layer sampler installed in monitoring well MW-54. Because of the limited amount of data collected during the demonstration and operational problems with the NoVOCs™ system throughout the demonstration, trends in the VOC concentration data associated with operation of the NoVOCs™ system were not apparent.

3.2.2.2 Secondary Objective S2

Document changes in SVOCs and selected geochemical parameters that may be affected by the NoVOCs™ system.

This objective was evaluated by collecting groundwater samples at the beginning and end of the demonstration from piezometers PZ-01 and PZ-02 and monitoring wells MW-45 through MW-54 and

TABLE 10

1,1-DICHLOROETHENE CONCENTRATION SUMMARY
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Well	Description	1,1-Dichloroethene Concentration (Fg/L)										
		Bechtel Baseline 2/6-10/98	Bechtel 3/4/98	Bechtel 3/19/98	Tetra Tech Baseline 4/17/98	Tetra Tech 1st Weekly 4/28/98	Bechtel 4/29/98	Tetra Tech 2nd Weekly 5/6/98	Tetra Tech 3rd Weekly 5/12/98	Tetra Tech 1st Monthly 6/8-10/98	Bechtel 6/8/98	Tetra Tech Baseline 9/8/98
PZ-01	System Recharge	**1,500**	**270**	**50**	**36**	**25**	**30**	**16**	**26**	**9.3**	**34**	**420**
PZ-02	System Intake	**6,100**	**2,700**	**2,800**	**81**	**2,300**	**4,400**	**2,400**	**3,100**	**4,300**	**5,400**	**6,100**
MW-45	Shallow Well	**340**	NA	NA	**500**	NA	NA	NA	NA	**930**	**1,600**	**850**
MW-46	Intermediate Well	**470**	NA	NA	**120**	NA	NA	NA	NA	**99**	**200**	**70**
MW-47	Deep Well	**10,000**	NA	NA	**9,300**	NA	NA	NA	NA	**5,300**	**7,600**	**540**
MW-48	Shallow Well	**430**	NA	NA	**160**	NA	NA	NA	NA	**150**	**260**	**530**
MW-49	Deep Well	**700**	NA	NA	**280**	NA	NA	NA	NA	**250**	**270**	**360**
MW-50	Intermediate Well	**210**	NA	NA	**180**	NA	NA	NA	NA	**25**	**210**	**260**
MW-51	Intermediate Well	**110**	NA	NA	**93**	NA	NA	NA	NA	**140**	**130**	**120**
MW-52	Shallow Well	NA	**18**	NA	<500	NA	NA	NA	NA	<500	**10 J**	<360
MW-53	Deep Well	NA	**20,000**	NA	NA(1)	NA	NA	NA	NA	**13,000**	**14,000**	**15,000**
MW-54	Fully Penetrating Well	NA	NA	NA	NA(2)	NA	NA	NA	NA	**6,000**	NA	**5,600**

Notes:

J Laboratory qualifier indicating the associated numerical value is an estimated quantity
Fg/L Micrograms per liter
< Less than
NA Not analyzed
(1) Monitoring well MW-53 was not sampled because of a malfunctioning bladder pump.
(2) Monitoring well MW-54 was not sampled because of the presence of the multi-level diffusion sampler in the well
Bolded values are above the reporting limit

TABLE 11

CIS-1,2-DICHLOROETHENE CONCENTRATION SUMMARY
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Well	Description	Cis-1,2-Dichloroethene Concentration (Fg/L)										
		Bechtel Baseline 2/6-10/98	Bechtel 3/4/98	Bechtel 3/19/98	Tetra Tech Baseline 4/17/98	Tetra Tech 1st Weekly 4/28/98	Bechtel 4/29/98	Tetra Tech 2nd Weekly 5/6/98	Tetra Tech 3rd Weekly 5/12/98	Tetra Tech 1st Monthly (6/8-10/98)	Bechtel 6/8/98	Tetra Tech Baseline 9/8/98
PZ-01	System Recharge	**6,300**	**6,700**	**2,100**	**2,400**	**1,800**	**1,500**	**1,200**	**1,500**	**580**	**1,100**	**3,800**
PZ-02	System Intake	**35,000**	**13,000**	**40,000**	**2,600**	**45,000**	**52,000**	**39,000**	**40,000**	**46,000**	**53,000**	**41,000**
MW-45	Shallow Well	**560**	NA	NA	**720**	NA	NA	NA	NA	**1,000**	**1,200**	**1,100**
MW-46	Intermediate Well	**66**	NA	NA	**130**	NA	NA	NA	NA	**3,200**	**3,800**	**1,700**
MW-47	Deep Well	**96,000**	NA	NA	**86,000**	NA	NA	NA	NA	**36,000**	**39,000**	**7,900**
MW-48	Shallow Well	**460**	NA	NA	**640**	NA	NA	NA	NA	**560**	**610**	**510**
MW-49	Deep Well	**440**	NA	NA	**2,100**	NA	NA	NA	NA	**880**	**840**	**1,300**
MW-50	Intermediate Well	**320**	NA	NA	**230**	NA	NA	NA	NA	**220**	**250**	**240**
MW-51	Intermediate Well	**180**	NA	NA	**200**	NA	NA	NA	NA	**270**	**290**	**260**
MW-52	Shallow Well	NA	**140**	NA	**120**	NA	NA	NA	NA	**150**	**160**	**250**
MW-53	Deep Well	NA	**68,000**	NA	NA(1)	NA	NA	NA	NA	**53,000**	**56,000**	**52,000**
MW-54	Fully Penetrating Well	NA	NA	NA	NA(2)	NA	NA	NA	NA	**6,400**	NA	**38,000**

Notes:

Fg/L Micrograms per liter
< Less than
NA Not analyzed
(1) Monitoring well MW-53 was not sampled because of a malfunctioning bladder pump.
(2) Monitoring well MW-54 was not sampled because of the presence of the multi-level diffusion sampler in the well.
Bolded values are above the reporting limit

TABLE 12

TRICHLOROETHENE CONCENTRATION SUMMARY
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Well	Description	Trichloroethene Concentration (Fg/L)										
		Bechtel Baseline 2/6-10/98	**Bechtel 3/4/98**	**Bechtel 3/19/98**	**Tetra Tech Baseline 4/17/98**	**Tetra Tech 1st Weekly 4/28/98**	**Bechtel 4/29/98**	**Tetra Tech 2nd Weekly 5/6/98**	**Tetra Tech 3rd Weekly 5/12/98**	**Tetra Tech 1st Monthly (6/8-10/98)**	**Bechtel 6/8/98**	**Tetra Tech Baseline 9/8/98**
PZ-01	System Recharge	**3,600**	**190**	**65**	**53**	**50**	**25**	**26**	**27**	**9.2**	**18**	**330**
PZ-02	System Intake	**740**	**790**	**1,300**	**120**	**760**	**1,600**	**1,900**	**2,000**	**2,300**	**1,700**	**7,800**
MW-45	Shallow Well	**10,000**	NA	NA	**11,000**	NA	NA	NA	NA	<330	**13,000**	**10,000**
MW-46	Intermediate Well	**1,300 E**	NA	NA	**1,800**	NA	NA	NA	NA	**770**	**950**	**550**
MW-47	Deep Well	**4,800**	NA	NA	**5,700**	NA	NA	NA	NA	**17,000**	**20,000**	**95**
MW-48	Shallow Well	**3,400**	NA	NA	**2,900**	NA	NA	NA	NA	**3,300**	**3,800**	**2,700**
MW-49	Deep Well	**7,900**	NA	NA	**2,400**	NA	NA	NA	NA	**1,200**	**1,300**	**1,700**
MW-50	Intermediate Well	**2,300**	NA	NA	**1,100**	NA	NA	NA	NA	**170**	**790**	**1,200**
MW-51	Intermediate Well	**3,300**	NA	NA	**3,200**	NA	NA	NA	NA	<100	**3,700**	**3,900**
MW-52	Shallow Well	NA	**4,800**	NA	**7,000**	NA	NA	NA	NA	**8,200**	**5,200**	**6,400**
MW-53	Deep Well	NA	**6,000**	NA	NA[1]	NA	NA	NA	NA	**2,100**	**2,100**	**1,200**
MW-54	Fully Penetrating Well	NA	NA	NA	NA[2]	NA	NA	NA	NA	**740**	NA	**1,400**

Notes:
D Laboratory qualifier identifies compounds in an analysis at a secondary dilution
E Value estimated because of interference
Fg/L Micrograms per liter
< Less than
NA Not analyzed
[1] Monitoring well MW-53 was not sampled because of a malfunctioning bladder pump.
[2] Monitoring well MW-54 was not sampled because of the presence of the multi-level diffusion sampler in the well.

analyzing the samples for SVOCs, dissolved metals, dissolved organic carbon, alkalinity, and total dissolved solids. In addition, groundwater samples were collected during the weekly sampling events from PZ-01 and PZ-02 and the monthly event from PZ-01 and PZ-02 and monitoring wells MW-45 through MW-54. These samples were analyzed for dissolved oxygen, oxidation/reduction potential, temperature, specific conductance, salinity, and pH. The results documenting SVOC concentrations and the selected geochemical characteristics are presented in Volume I, Appendix A as Tables A3 through A35, and are discussed below.

The only SVOC detected on a consistent basis was 1,2-dichlorobenzene. Based on the review of the 1,2-dichlorobenzene concentration data, no clear trends were identified that indicated that contaminant concentrations were affected by the operation of the NoVOCs™ system.

Despite the possible iron fouling problems experience in the NoVOCs™ well, the groundwater analytical results for dissolved metals exhibited no clear trends in the data to indicate the precipitation of dissolved metals was occurring in the aquifer. Alkalinity, total organic carbon, and dissolved organic carbon results remained relatively unchanged during the demonstration. Total dissolved solid concentrations showed an increasing trend with depth; however, concentrations did not appear to be affected by operation of the NoVOCs™ system. Conductivity and salinity values measured in the field also increased with depth and appeared to correlate with the analytical results for total dissolved solids. No clear trends were apparent from the field measurements of temperature, pH, and dissolved oxygen, and insufficient data were collected to adequately evaluate trends associated with oxidation/reduction potential.

In addition to the select geochemical parameters analyzed during collection of groundwater samples, water quality parameters, including temperature, specific conductance, pH, oxidation/reduction potential, dissolved oxygen, salinity, and turbidity were measured in water from the pump discharge line during the pumping tests. A summary of the water quality parameter measurements is provided in the Hydrogeologic Investigation of the Aquifer Treated by the NoVOCs™ System (Tetra Tech 2000), which is provided as Volume I, Appendix C. In general, results for the water quality parameters have higher values in the lower screened zone, with the exception of pH and temperature. This finding was also supported for the VOC concentration data from the wells at the demonstration site, which exhibit higher concentrations in samples from the deep wells than in samples from the shallow wells.

Specific conductance and salinity values measured during pumping of the upper screened interval averaged 22.2 micromhos per centimeter (Fmhos/cm) and 2.26 percent, respectively, while the same parameters measured during pumping of the lower screen interval averaged 27.4 Fmhos/cm and 2.71 percent. These results are consistent with the range of values and trend toward increased specific conductance and salinity with depth. Average temperature measured while pumping the upper and lower screened intervals was about 21.7 EC. Results of pH measurements while pumping the upper screened interval averaged 7.40, which was higher than the average pH value of 7.03 calculated from measurements collected when pumping the lower screened interval. The average oxidation/reduction potential in the upper interval was 22.7 millivolts (mV), while the average oxidation/reduction potential (Eh) in the lower interval was minus 30.5 mV. Dissolved oxygen concentrations remained relatively unchanged between the two screened intervals.

3.2.2.3 Secondary Objective S3

Document NoVOCs™ system operating parameters.

The following process data were provided by Bechtel:

- Air temperature measurement at the well air intake, after the blower and before injection into the well
- Pressure measurement after the blower and before injection into the well
- Linear flow velocity measurement after the blower and before injection into the well
- Well pumping rate measurement using an in-well flow sensor
- Groundwater pH measurement in the well effluent

A summary of the system operating parameter results is shown in Table 13.

TABLE 13

NoVOCs™ SYSTEM OPERATING PARAMETERS
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Operating Period	Dates of Operation	Well Air Intake						Well		Well Effluent	
		Temperature (EF)		Pressure (psi)		Air Flow (scfm)		Pumping Rate (gpm)		pH	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Startup and Shakedown Operation	February 26 through March 26, 1998	145	103 to 180	2.8	2.2 to 3.6	66.7	40 to 120	22.2	8 to 34	7.28	5.36 to 12.35
Early Operation	April 20 through June 19, 1998	132	66 to 184	3.3	3.0 to 3.6	55.8	51 to 65	15.0	10 to 24	6.54	1.23 to 7.76
Reconfiguration Operation	September 24 through October 30, 1998	152	120 to 173	2.8	2.5 to 3.3	69.0	35 to 90	18.4	14 to 22	7.10	6.40 to 7.62
Final Configuration Operation	December 1, 1998 through January 4, 1999	136	119 to 150	3.0	3.0 to 3.0	52.4	50 to 55	NR	NR	3.60	1.25 to 7.5

Notes:

psi Pounds per square inch
scfm Standard cubic feet per minute
gpm Gallons per minute
NR Not reported

3.2.2.4 Secondary Objective S4

Document pre- and post-treatment VOC concentrations and system operating parameters in the Thermatrix flameless oxidation offgas treatment system.

This objective was evaluated by collecting duplicate, 1-hour integrated air samples from sampling ports A3 (pretreatment) and A4 (post-treatment) and analyzing samples for VOCs using EPA Method TO-14.

In addition to pre- and post-treatment VOC concentrations, air flow rate, vacuum, and temperature were recorded at sampling ports A3 and A4 (see Figure 4). A total of five air sampling and flow rate measurement events were conducted during the demonstration; once per week during the first month (four events) and one monthly event. Additional samples were not collected because of system operational problems encountered during the demonstration. A summary of the VOCs detected and flow rate measurements collected from air sampling ports A3 and A4 are provided in Tables 14 and 15, respectively.

Based on a comparison of influent and effluent samples collected from the Thermatrix system, total VOC concentrations in the 1-hour composite samples collected from the influent air sampling port (A3) ranged from 22,120 to 59,200 ppb v/v and averaged 45,200 ppb v/v during the five sampling events. Total VOC concentrations in the 1-hour composite samples collected from the effluent air sampling port (A4) ranged from 2.8 to 7.2 ppb v/v and averaged 4.8 ppb v/v during the five sampling events. Total VOCs concentrations measured in the influent sampling port were reduced by greater than 99.9 percent in all five sampling events.

3.2.2.5 Secondary Objective S5

Document the hydrogeologic characteristics at the treatment site.

This objective was evaluated by conducting a series of aquifer tests at the demonstration site from July 27 through August 5, 1998, to obtain information on hydraulic communication between various zones of the aquifer beneath the site, as well as data for estimating values of aquifer hydraulic parameters such as hydraulic conductivity, transmissivity, storativity, specific yield, and anisotropy. In addition, the aquifer

TABLE 14

AIR SAMPLE RESULTS – THERMATRIX INFLUENT SAMPLING PORT A3
NoVOCS™ SITE Demonstration
Site 9, NAS North Island, California

Chemical Parameters	Sampling Event				
	1st Weekly 4/28/98	**2nd Weekly 5/6/98**	**3rd Weekly 5/12/98**	**4th Weekly 5/21/98**	**1st Monthly 6/8/98**
Volatile Organic Compounds (ppb v/v)					
Benzene	<1,100	<760	<1,100	<760	<1,100
Chlorobenzene	<1,100	<760	<1,100	<760	<1,100
Chloroform	<1,100	<760	<1,100	<760	<1,100
Dichlorodifluoromethane	<1,100	<760	<1,100	<760	<1,100
1,1-Dichloroethene	**7,900**	**5,600**	**7,600**	**4,800**	**2,700**
Cis-1,2-Dichloroethene	**47,000**	**37,000**	**48,000**	**32,000**	**18,000**
Tetrachloroethene	<1,100	<760	<1,100	<760	<1,100
Toluene	<1,100	<760	<1,100	<760	<1,100
Trichloroethene	**2,000**	**1,500**	**1,900**	**1,200**	**680**
1,1,2-Trichloro-1,2,2-trifluoroethane	**2,300**	**1,500**	**2,200**	**1,400**	**740**
1,2,4-Trimethylbenzene	<1,100	<760	<1,100	<760	<1,100
1,3,5-Trimethylbenzene	<1,100	<760	<1,100	<760	<1,100
m- and p-Xylenes	<1,100	<760	<1,100	<760	<1,100
Total VOCs	**59,200**	**45,600**	**59,700**	**39,400**	**22,120**
Physical Parameters					
Pressure in inches WC	NA	25.3	24.5	22	21
Flowrate in scfm	NA	58	60	NA	61

Notes:
< Less than
NA Not analyzed
ppb v/v Parts per billion on a volume per volume basis
scfm Standard cubic feet per minute
VOC Volatile organic compounds
WC Water column
Bolded values are above the reporting limit

TABLE 15

AIR SAMPLE RESULTS – THERMATRIX EFFLUENT SAMPLING PORT A4
NoVOCS™ SITE Demonstration
Site 9, NAS North Island, California

Chemical Parameters	Sampling Event 1st Weekly 4/28/98	2nd Weekly 5/6/98	3rd Weekly 5/12/98	4th Weekly 5/21/98	1st Monthly 6/8/98
Volatile Organic Compounds (ppb v/v)					
Benzene	<6.6	**0.88 B, N**	<1.2	<0.63	<0.51
Chlorobenzene	<6.6	**1.1 B, N**	<1.2	<0.63	<0.51
Chloroform	**1.0**	**1.9**	<1.2	**3.9**	**3.4 B**
Dichlorodifluoromethane	<6.6	<0.54	<1.2	<0.63	<0.51
1,1-Dichloroethene	<6.6	<0.54	<1.2	<0.63	<0.51
Cis-1,2-Dichloroethene	<6.6	<0.54	<1.2	<0.63	**2.4 B, N**
Tetrachloroethene	**97 B, N**	<0.54	<1.2	<0.63	<0.51
Toluene	**6.2**	**1.8 B, N**	**3.3 B, N**	**2.4 B, N**	**0.80 B, N**
Trichloroethene	<6.6	<0.54	<1.2	<0.63	<0.51
1,1,2-Trichloro-1,2,2-trifluoroethane	<6.6	<0.54	<1.2	<0.63	<0.51
1,2,4-Trimethylbenzene	<6.6	**2.8**	**0.95**	<0.63	<0.51
1,3,5-Trimethylbenzene	<6.6	**1.1**	<1.2	<0.63	<0.51
m- and p-Xylenes	<6.6	**1.1**	**1.8**	**0.93 B, N**	<0.51
Total VOCs	**7.2 B**	**6.9**	**2.8**	**3.9**	**3.4 B**
Physical Parameters					
Pressure in inches WC	NA	NA	NA	NA	NA
Flowrate in scfm	NA	NA	NA	NA	NA

Notes:
B Blank contamination; result may be biased high
N Data judged not usable due to indicated data quality problem
< Less than
NA Not analyzed
ppb v/v Parts per billion on a volume per volume basis
scfm Standard cubic feet per minute
VOC Volatile organic compounds
WC Water column
Bolded values are above the reporting limit

tests were conducted to obtain data for calculating well efficiencies for the two screened intervals of the NoVOCs™ well.

Aquifer testing was conducted using the NoVOCs™ well (IW-01) as the pumping or injection well. Two piezometers and 10 observation wells were available for water level measurements. An inflatable packer was used to isolate the two screened intervals within the NoVOCs™ well to allow pumping from each screened interval separately. The aquifer tests, in the order conducted, were as follows:

- Step drawdown test in the upper screened interval conducted on July 27, 1998
- A 32-hour constant discharge pumping test in the upper screened interval conducted on July 28 and 29, 1998
- Injection test in the upper screened interval conducted on July 31, 1998
- Step drawdown test in the lower screened interval conducted on August 1, 1998
- Dipole flow test with pumping in the lower screened interval and injection in the upper screened interval conducted on August 5, 1998

A constant discharge pumping test for the lower screened interval was not conducted because of the excessive volume of water that would be generated and the prohibitive cost of water disposal. A detailed description of the methods, procedures, results, and interpretation of the hydrogeologic study is presented in the Hydrogeological Investigation Report of the Aquifer Treated by the NoVOCs™ System (Tetra Tech 2000), which is provided as Volume I, Appendix C. The conclusions of the hydrogeologic study are summarized below.

- Groundwater generally flows to the west or northwest in both of the upper and lower aquifer zones. The horizontal hydraulic gradient in both aquifer zones is relatively flat, ranging from 0.005 to 0.01.
- Aquifer hydraulic parameters are estimated based on the tidally corrected groundwater drawdown data for the constant discharge pumping test conducted at the upper well screen. The average hydraulic conductivity is 29 ft/day or 0.01 cm/sec. The average aquifer storativity and specific yield are 0.004 and 0.07, respectively. The average ratio of horizontal to vertical hydraulic conductivity is 5.7.
- Specific capacity and efficiency of the NoVOCs™ well are estimated based on the step-drawdown tests and water injection test conducted at the NoVOCs™ well. The calculated average specific capacities are 1.48 gallons per minute per foot (gpm/ft) for the upper screened

interval during pumping, 1.50 gpm/ft for the upper screened interval during injection, and 3.22 gpm/ft for the lower screened interval during pumping. The calculated average well efficiencies are 82 percent for the upper screened interval during pumping, 97 percent for the upper screened interval during injection, and 91 percent for the lower screened interval during pumping. The 97 percent well efficiency for the upper screened injection is for injection of clean tap water.

C The radius of influence during the constant discharge pumping test (20 gpm) is at least 100 feet based on the drawdown measured at the observation wells.

C The injection test results show that the maximum flow of clean tap water that can be injected through the upper screen of the NoVOCs™ well is 25 gpm. At that injection rate, the water level will rise 17 feet and reach the ground surface.

C The findings of the aquifer tests and tidal study of the aquifer treated by the NoVOCs™ system indicate that the aquifer hydraulic conditions are suitable for application of the NoVOCs™ technology. The NoVOCs™ well as designed should be able to extract and inject a flow rate of 20 gpm based on the aquifer hydraulic characteristics.

3.2.2.6 Secondary Objective S6

Document the changes in pressure head in the aquifer caused by the NoVOCs™ system.

This objective was achieved by conducting a tidal influence study from April 20 through 30, 1998, to measure natural fluctuations in water level at the site caused by tidal influences and water level changes in the aquifer caused by NoVOCs™ system operation. A description of the methods and procedures used to conduct the tidal study is presented in the Hydrogeological Investigation of the Aquifer Treated by the NoVOCs™ System (Tetra Tech 2000), which is provided as Volume I, Appendix C. The results of the study are summarized below.

Maximum groundwater level fluctuations measured in the observation wells ranged from 0.56 to 0.73 feet, depending on the location of the observation well. The amplitudes of the tidal fluctuations in water levels were highest for observation wells closest to San Diego Bay (MW-52 and MW-53). The other observation wells monitored during the tidal influence study (MW-45 through MW-51) are all located at approximately the same distance from San Diego Bay; the amplitudes of the tidal fluctuations in these wells are similar.

The cyclical pattern of groundwater level fluctuation can be seen for all observation wells and correlates with published tide charts for San Diego Bay with a time lag ranging from about 46 to 96 minutes, depending on observation well location and magnitude of the tidal fluctuation. The time lag also depends on the degree of hydraulic communication between the bay and the wells. The range of time lags is similar for each of the observation wells because of the similar distance relative to San Diego Bay. The aquifer zone is generally in good hydraulic communication with the San Diego Bay.

Groundwater level changes caused by startup and shutdown of the NoVOCs™ system on April 20, 1998, are evident in the water level data for well cluster MW-45, MW-46, and MW-47, located about 30 feet from the NoVOCs™ well. The water level data for observation wells MW-45 (the upper screened well in this cluster) and MW-46 (intermediate screened well) show water level increases after system startup. The groundwater elevation increase in well MW-45 was approximately 0.15 feet of water. Observation well MW-46, the intermediate depth well, shows a water level increase of approximately 0.05 feet of water. Observation well MW-47, the deep screened well, shows a water level decrease of approximately 0.025 feet. This pattern of water level increases and decreases associated with the operation of the NoVOCs™ system is expected based on the monitoring well screen locations relative to the NoVOCs™ well screen locations. The deep screened well experienced a drop in water level as water was drawn toward the NoVOCs™ well intake, and the upper screened wells experienced increases in water level as water was lifted inside of the NoVOCs™ well, and discharged into the upper aquifer. In well pair MW-48 and MW-49 (located about 62 feet from the NoVOCs™ well) and in wells MW-50 and MW-51 (located about 91 and 105 feet, respectively, from the NoVOCs™ well), water level changes associated with NoVOCs™ system operation were not apparent. Similar results were observed during the dipole test conducted in August 1998.

3.2.2.7 Secondary Objective S7

Estimate the capital and operating costs of the NoVOCs™ system and Thermatrix flameless oxidation process for the 6 month evaluation.

This objective was evaluated by using capital and operating and maintenance cost information provided by the Navy and MACTEC and by estimating labor requirements. A detailed estimate of the costs of installing and operating a single NoVOCs™ well to treat groundwater contaminated with VOCs is presented in Section 4.0.

3.3 DATA QUALITY

This section summarizes the data quality for groundwater and air samples collected and analyzed during the NoVOCs™ technology demonstration. This data quality assessment was conducted to evaluate the impact of all QC measures on the overall data quality, and remove all unusable values from the investigation data set. The results of this assessment were used to produce the known, defensible information employed to define the investigation findings and draw conclusions.

Both field QC samples and laboratory QC analyses were analyzed. Field samples included equipment blanks, field blanks, and trip blanks. Laboratory samples included method blanks, surrogate recoveries, initial and continuing calibration, matrix spike/matrix spike duplicates, and samples/sample duplicates. Results from these samples were used to evaluate the precision and accuracy of the data.

Summaries of analytical QC data are provided in Volume VI, Appendix F. In general, all data quality indicators met the QA objectives specified in the TEP/QAPP (Tetra Tech 1998) for the NoVOCs™ technology demonstration, indicating that general data quality was good and that the sample data are useable as reported. The data quality indicators associated with the baseline, first, second, third, and fourth weekly, first monthly, and second baseline sampling events met the acceptance criteria specified in the QAPP (Tetra Tech 1998). Data quality outliers from the other sampling events are identified and discussed in Table 16. None of the outliers discussed in Table 16 were determined to inhibit the overall usefulness of the demonstration data in evaluating the demonstration project objectives.

Additionally, QC control charts of precision and accuracy for VOCs, as determined by matrix spike (MS) recoveries and matrix spike/matrix spike duplicates (MS/MSD) RPDs, were prepared to assess potential trends in analytical system bias. These charts did not reveal noticeable trends in system bias, suggesting that trends noted from demonstration data are due to contaminant concentration changes in the environmental media sampled.

TABLE 16

DATA QUALITY OUTLIERS
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Sampling Event	Data Quality Outlier	Impact on Data Quality
Critical Parameters		
Baseline	Several groundwater samples required dilution to bring high concentration analytes (particularly cis-1,2-dichloroethene) into the calibration range of the instrument.	The dilutions resulted in elevated detection limits for other analytes, but this occurrence was anticipated in the QAPP, and an undiluted sample was run if such an analysis appeared to be warranted to achieve lower detection limits.
	Method blanks and the trip blank revealed persistent low-level contamination (below the laboratory reporting limit) of methylene chloride, a common laboratory solvent.	Sample results were flagged with respect to the observed concentrations of methylene chloride. Because methylene chloride was not a significant fraction of the total measured chlorinated hydrocarbons in any of the contaminated groundwater samples and is not a critical analyte, the potential high bias of the methylene chloride results should not affect overall project objectives.
First Weekly	Tetrachloroethene contamination was observed in the field blank at a significant level. Tetrachloroethene was also detected once in the Thermatrix stack gas (Location A4), even though it was not detected in the influent to the Thermatrix system (Location A3) or in the groundwater passing through the NoVOCs™ system (Locations A1 and A2).	The one tetrachloroethene measurement in the Thermatrix stack gas has been flagged because it may reflect sample contamination.

TABLE 16 (Continued)

DATA QUALITY OUTLIERS
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Sampling Event	Data Quality Outlier	Impact on Data Quality
First Weekly	Method blanks and the trip blank revealed persistent trace level contamination (below the laboratory reporting limit) of methylene chloride, a common laboratory solvent.	Sample results were flagged with respect to the observed concentrations of methylene chloride. Because methylene chloride was not a significant fraction of the total measured chlorinated hydrocarbons in any of the contaminated groundwater samples, the potential high bias of the methylene chloride results should not affect overall project objectives.
Third Weekly	Small quantities of BTEX were observed in the field blank.	Because BTEX compounds were observed only in the Thermatrix effluent vapor (sampling location A4) and not in the Thermatrix influent vapor (sampling locations A2 and A3), it appears that BTEX concentrations in the A4 sample may be related to either field contamination or to improper cleaning of summa canisters. These results have been flagged and will not be used in the data analysis.
Fourth Weekly	Small quantities of BTEX compounds were observed in the field blank.	Because BTEX compounds were observed above the reporting limit in the Thermatrix effluent vapor (sampling location A4) and influent air (sampling location A1) but not in the Thermatrix influent vapor (sampling locations A2 and A3), it appears that BTEX concentrations in the A4 and A1 samples may be related to either field contamination or more specifically to improper cleaning of summa canisters. These results have been flagged and will not be used in the data analysis.

TABLE 16 (Continued)

DATA QUALITY OUTLIERS
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Sampling Event	Data Quality Outlier	Impact on Data Quality
First Monthly	Small quantities of several critical BTEX analytes (benzene, toluene, and xylenes) and chlorinated hydrocarbons (cis-1,2-dichloroethene and tetrachlorothene) were observed in the field blank.	This was likely due to insufficient cleaning of Summa canisters at the laboratory prior to the sampling event. Because the contaminants were detected in the field blank at concentrations well below the detection limits of the high level samples (A2 and A3), this should have no significant impact on data quality for these samples. However, results for any of these compounds that were detected in the low-level samples (A1 and A4) have been flagged with a B, noting that the reported result may be biased high due to blank contamination. Removal efficiencies that will be calculated for the Thermatrix combustion system may therefore be biased low. However, preliminary calculations indicate that these removal efficiencies will be greater than 99 percent, so that the impact of low-level field blank contamination is relatively minor.
Non-Critical Parameters		
Baseline	Matrix spike results for the metals analysis revealed some recoveries outside of the laboratory's control limits.	No QA objectives for accuracy or precision were set in the QAPP for this noncritical analysis. In addition, the few exceptions to the laboratory's QC acceptance criteria were minor deviations or appeared to involve low spike levels relative to background metal concentrations. Therefore, no qualifications of this data appear to be warranted.

4.0 ECONOMIC ANALYSIS

This section presents an economic analysis of the NoVOCs™ technology for treating groundwater contaminated with VOCs. The economic analysis is based on assumptions and cost data provided by the Navy and MACTEC and on the results and experience gained from the SITE evaluation that was conducted at NAS North Island, Site 9. Some cost assumptions are based on previous experience with economic analyses for demonstrations involving similar groundwater circulation wells evaluated under the SITE Program. Costs for the economic analysis have been assigned to one of 12 categories applicable to cleanup activities at Superfund and Resource Conservation and Recovery Act (RCRA) sites (Evans 1990). This section provides a discussion of each category, including general and specific impacts on the overall cost and the assumptions used in the economic analysis.

The MACTEC NoVOCs™ system is applicable principally to groundwater contaminated with VOCs such as solvents and gasoline. A number of factors could affect the cost of treatment, including soil type; contaminant type and concentration; depth to groundwater; site geology and hydrology; groundwater geochemistry; site size and accessibility; required support facilities and available utilities; and treatment goals. It is important to characterize the site thoroughly and properly before implementing this technology to ensure that treatment is focused on contaminated areas and to determine the zone of influence for the well and the number of wells needed to remediate a particular site. Site characterization costs may be substantial, but are not included in this cost analysis.

An economic analysis for treating a portion of the aquifer with a single NoVOCs™ well located immediately downgradient of a contaminant source area was conducted, assuming site conditions and technology performance similar to those encountered during the SITE demonstration at NAS North Island, Site 9. Costs are presented in this economic analysis are in 1999 dollars and are considered to be order-of-magnitude estimates, with an accuracy of plus 50 percent and minus 30 percent.

4.1 BASIS OF ECONOMIC ANALYSIS

This section describes the factors that affect the costs associated with the NoVOCs™ system and presents the assumptions used in this economic analysis. A number of factors affect the estimated costs of treating groundwater with the NoVOCs™ system, including (1) operating, maintenance, and monitoring factors and (2) site conditions and system design.

4.1.1 Operating, Maintenance, and Monitoring Factors

Operating, maintenance, and monitoring costs are highly variable because of the site-specific and time-dependent nature of NoVOCs™ operation required to remediate a site. The duration of operation for the remediation of a site using the NoVOCs™ system depends on a number of factors, including: (1) the mass and physical characteristics of contaminants present, (2) efficiency of the NoVOCs™ system in removing specific contaminants, (3) site treatment goals, and (4) the aquifer hydrogeologic characteristics. These factors are discussed in detail below.

The mass and physical characteristics of the contaminants in the aquifer to be remediated affect the operation time by influencing the exchange of contaminants from the dissolved to vapor phase. Groundwater with high concentrations of contaminants and contaminants in phases other than the dissolved phase may require multiple passes of recirculated water through the treatment system to meet the target treatment concentration goals. The increased time needed for multiple passes through the treatment system will increase the total cost of operation, maintenance, and monitoring.

The treatment efficiency of each NoVOCs™ well system is dependent on adjustments to design factors (such as air to water ratio). Systems that are not properly adjusted will not achieve maximum efficiency in removing contaminants. Compounds with low removal efficiencies or high influent concentrations may require multiple passes through the treatment system to meet target treatment concentration goals. Again, the increased time needed for multiple passes through the treatment system will increase the total cost of operation, maintenance, and monitoring.

Aquifer hydrogeologic characteristics affect the operation time by controlling (1) the extent of the circulation cell and capture zone, (2) the amount of water that can be pumped through the treatment system per unit time, and (3) the amount of recirculated water passing through the system. The extent of the circulation cell and capture zone is primarily affected by the anisotropy of the aquifer; the ratio of the hydraulic conductivity in the horizontal direction to that in the vertical direction. Anisotropic conditions within the aquifer will result in differences in hydraulic conductivity and groundwater flow within the aquifer. A NoVOCs™ well installed within an aquifer with a high anisotropy ratio will typically have a larger zone of influence radius than an aquifer with a low anisotropy. Additionally, aquifers with low horizontal hydraulic conductivity may require the NoVOCs™ system to operate at a reduced pumping rate. Furthermore, an aquifer with a low anisotropy ratio typically has a high degree of recirculation through the system and a smaller percentage of untreated water entering the system. Aquifers with high anisotropy ratios typically have a low degree of recirculation through the system and a larger percentage of untreated water entering the system. The vendor reports typical recirculation amounts of treated water ranging from 60 to 90 percent. A small zone of influence may require multiple treatment wells to be installed if the aerial extent of contamination exceeds the zone of influence, and high degrees of recirculation may increase the operation time required to remediate an aquifer. Extra treatment wells and extended treatment time will increase the total cost of the operation, maintenance, and monitoring.

Routine maintenance inspections of the NoVOCs™ system are recommended at least once a week. System maintenance may be increased during the initial startup phase of operation to ensure that the system is working properly. After the initial startup period, however, the vendor claims that no daily requirements for operation and maintenance exist.

Requirements for monitoring the system's performance will vary between sites. Most sites will require monitoring of the treated and untreated groundwater, the system's effluent air stream, and the groundwater in surrounding monitoring wells.

4.1.2 Site Conditions and System Design Factors

The number of NoVOCs™ systems employed at the site will affect the duration and cost of a groundwater remediation project. The need to use more than one treatment system is determined based on site conditions. This analysis assumes that only one NoVOCs™ system will be installed to treat groundwater contaminated with VOCs.

Typically, system design costs for Superfund sites include site preparation (such as removal of debris), construction activities (such as access roads), and site characterization. These costs are not included in this analysis because they are assumed to have been incurred while characterizing the extent of groundwater contamination. However, additional costs incurred for site preparation, construction, and monitoring well installation activities specifically associated with installation and monitoring of the NoVOCs™ system are included in the economic analysis.

Assumptions for site conditions and system design include the following:

- The site is a Superfund site with PCE-, TCE-, 1,1-DCE-, and BTEX-contaminated groundwater.
- The aquifer has been characterized during previous investigations.
- Suitable site access roads exist.
- Utility supply lines, such as electricity and telephone lines, exist on site.
- A single, 8-inch-diameter NoVOCs™ system will be used for treatment.
- The treatment system will be install at a depth of 80 feet bgs and will operate automatically.
- Contaminated groundwater is located in a shallow aquifer no more than 40 feet bgs.
- The saturated zone has a depth of about 40 feet.
- The flow rate through the NoVOCs™ system is 20 gpm.
- The unit operates 95 percent of the time with only 5 percent downtime for maintenance and repairs.
- Operation and maintenance requires two field technicians to be on site 1 day a week, 8 hours a day.
- One technician is required to collect all required samples and perform minor equipment repairs at the same frequency used for maintenance.
- Untreated and treated groundwater and air samples will be collected from the NoVOCs™ well once per week for the first month and monthly thereafter. In addition, a total of 50 groundwater and air samples will be collected during system startup and shakedown.
- Eight groundwater monitoring wells will be installed to monitor the system's effect on the aquifer. Four of the wells will be installed to a depth of 40 feet bgs, and four wells will be installed at a depth of 80 feet bgs. The wells will be sampled quarterly.
- Only routine maintenance will be required. Labor, materials, and equipment costs associated with major repairs will not be incurred.
- An activated carbon offgas treatment system will be used to treat the air effluent generated by the NoVOCs™ system.

- Because of the nature of the NoVOCs™ technology, no site cleanup or restoration activities would be required during demobilization, except for well plugging and dismantling the offgas treatment unit.

- Because of the variable nature of the time required to remediate a site, annual operation and maintenance costs have been presented for operating the NoVOCs™ system for 1, 3, 5, and 10 years.

4.2 COST CATEGORIES

Cost data associated with the NoVOCs™ technology have been assigned to the following 12 categories: (1) site preparation; (2) permitting and regulatory requirements; (3) equipment; (4) startup; (5) labor; (6) consumables and supplies; (7) utilities; (8) effluent treatment and disposal; (9) residuals and waste shipping and handling; (10) analytical services; (11) maintenance and modifications; and (12) demobilization. Using the general assumptions already discussed, a breakdown of costs into the 12 categories is presented in Table 17. The assumptions used for each specific cost factor are discussed in more detail below.

4.2.1 Site Preparation Costs

Preliminary site preparation activities are generally highly specific, depending on a number of factors. For this analysis, generic site preparation activities, such as site design and layout, surveys and site logistics, legal searches, access rights, and roads were all assumed to be performed by the responsible party (or site owner) in conjunction with the vendor. None of these costs has been included in this economic analysis. Likewise, site characterization costs were not included in this cost analysis. Site characterization can add substantially to project costs. The following site characterization information should be available before designing and installing a NoVOCs™ treatment system: (1) site geology, (2) site hydrology, (3) geochemistry, and (4) contaminant distribution.

The focus instead was on technology-specific site preparation costs. Site preparation costs include the drilling and preparation of a single, 8-inch-diameter NoVOCs™ well and eight, 2-inch-diameter monitoring wells, well installation and construction oversight, utility connections, fence installation, and

TABLE 17

COSTS ASSOCIATED WITH THE NoVOCs™ SYSTEM
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Cost Categories	Costs in 1999 Dollars[a]
1. Site Preparation[b]	$57,000
2. Permitting and Regulatory Requirements[b]	$15,000
3. Equipment[b]	$95,000
4. Startup[b]	$10,000
5. Labor[c]	$42,000
6. Consumables and Supplies[c]	$50,000
7. Utilities[c]	$11,000
8. Effluent Treatment and Disposal[c]	$8,000
9. Residual and Waste Shipping and Handling[c,d]	$13,000 ($3,000)
10. Analytical Services[c,e]	$28,000 ($21,000)
11. Maintenance and Modifications[c]	$10,000
12. Demobilization[b]	$14,000
Total One-time Costs	$190,000
First Year Operation and Maintenance Costs	$160,000
Subsequent Years' Annual Operation and Maintenance Costs	$150,000
Total Costs of Project Lasting 1 Year[f]	$350,000
Total Costs of Project Lasting 3 Years[f]	$670,000
Total Costs of Project Lasting 5 Years[f]	$1,000,000
Total Costs of Project Lasting 10 Years[f]	$2,000,000

Notes:

[a] Costs have been rounded to two significant digits
[b] One-time cost
[c] Annual variable operation and maintenance cost
[d] The figure represents residual and waste shipping and handling costs for the first year of operation. Annual residual and waste shipping and handling costs for successive years are estimated to be $3,000.
[e] The figure represents analytical service costs for the first year of operation. Annual analytical service costs for successive years are estimated to be $21,000.
[f] Accounts for an estimated annual inflation rate of 4 percent

auxiliary support buildings. These are generally one-time charges and will vary, depending on site-specific conditions and project requirements.

Assuming an average cost of $60 per feet, the drilling and installation costs for a NoVOCs™ well and eight monitoring wells is estimated to be $33,600 ($60/ft x 560 ft). Development of the wells is estimated to cost $4,200, assuming 3 days for development, 8 hours per day at a rate of $175 per hour. Well installation and construction oversight is estimated to cost $9,000, assuming two field technicians are required to work 9 days (6 days for well drilling and installation and 3 days for well development), 10 hours per day at a rate of $50 per hour. These cost included equipment mobilization to the site. Because installation was conducted by a local contractors, travel and per diem costs were not incurred.

According to Bechtel, costs associated with drilling, installation, and development of a single NoVOCs™ well installed at a depth of 80 feet bgs and 14 monitoring wells installed at depths ranging from 40 to 80 feet bgs during the SITE demonstration at NAS North Island were $110,000. Because of difficult drilling conditions encountered at Site 9, such as flowing sands, this cost may not be representative of typical site preparation costs.

Based on SITE demonstration experience, it was estimated that utility connections would cost about $6,000, assuming that an electrical connection is available within 200 feet of the system and no transformer is needed. A 6 by 8 by 8-foot support building to house miscellaneous equipment was estimated to cost $2,000. A fence to enclose the NoVOCs™ wellhead, monitoring wells, control trailer, and offgas treatment system is estimated to cost $2,000.

The total site preparation cost is estimated to be $56,800.

4.2.2 Permitting and Regulatory Requirements Costs

This category includes costs associated with system health and safety monitoring and analytical protocol development as well as permitting costs. Permitting and regulatory costs are site- and waste-specific and can vary, depending on whether treatment occurs at a Superfund or a RCRA corrective action site, and on state and local requirements. Superfund sites require remedial actions to be consistent with applicable or relevant and appropriate requirements (ARAR), including federal, state, and local standards and criteria.

In general, ARARs must be determined on a site-specific basis. RCRA corrective action sites would require additional permitting, monitoring, and records. Permits that may need to be considered for this technology include drilling and air discharge permits.

Permitting and regulatory costs include preparation of required regulatory documents and are estimated to be about $15,000. However, obtaining and complying with permits and any other regulatory standards could potentially be a very expensive and time consuming activity.

4.2.3 Equipment Costs

Equipment costs include the NoVOCs™ system and an offgas treatment system. Costs for equipment associated with monitoring wells are included in the installation costs presented in Section 4.2.1, Site Preparation Costs. Equipment for the NoVOCs™ system includes (1) hardware and materials, such as well screens and casing, well pack materials, and a wellhead seal; and (2) mechanical components, such as a control trailer, blower, gauges, control panels, meters, and pumps. Also included in the capital costs of the NoVOCs™ well are preliminary and final design of the well. Based on the SITE demonstration, hardware and material costs are estimated to be $10,000, and the mechanical components are estimated to be $50,000. Preliminary and final design will be conducted by a senior engineer and is estimated to require about 60 hours for preliminary design and 160 hours for final design. Assuming a labor rate of $90 per hour for a senior engineer, total design costs for a NoVOCs™ well are about $19,800. Total equipment cost for a NoVOCs™ system are estimated to be about $79,800.

The offgas treatment system for this economic analysis is assumed to consist of two 1,800-pound vapor-phase activated carbon units, ancillary piping connecting the carbon units to the NoVOCs blower, and activated carbon. Monthly carbon adsorption unit rental costs are discussed in Section 4.3.6, Consumables and Supplies Costs. It is estimated that the cost for this equipment will be about $15,000. The costs of disposing of or recharging the carbon are discussed in Section 4.2.8, Effluent Treatment and Disposal Costs.

Total equipment cost for the NoVOCs system and offgas treatment system is estimated to be $94,800.

4.2.4 Startup Costs

Startup costs include operator training, system optimization, and system shakedown costs. This analysis assumes that one operator must be trained. Operator training costs are assumed to require about 40 hours of training or about $2,000 assuming a labor rate of $50 per hour. Optimization and shakedown activities include initial startup, trial runs, final equipment inspection, and associated labor for conducting these activities. Based on SITE demonstration experience, it is estimated that these activities will require one person, 24 hours a day for 7 days. Assuming an average labor rate of $50 per hour, labor costs for system optimization and shakedown would be $8,400 (168 hours x $50 per hour).

Total startup costs are estimated to be about $10,400.

4.2.5 Labor Costs

Hourly labor rates for operation include base salary, benefits, overhead, and general and administrative expenses. Labor rates do not include travel, per diem, or rental car because it is assumed that labor would be hired locally. This cost analysis assumes that labor costs will be limited to system inspection, monitoring, adjustments, sampling, and minor maintenance and repair of equipment. To complete these labor requirements, it is estimated that it two field technicians will be on site 1 day a week for 8 hours. Assuming a labor rate of $50 per hour, weekly labor costs are estimated to be $800 or $41,600 annually.

4.2.6 Consumables and Supplies Costs

Consumables and supplies costs include renting activated carbon units to treat system offgas and acid and biocide solutions to control fouling of the NoVOCs™ well. Costs for personal protective equipment are included with the labor costs (see Section 4.2.5) presented above, and the costs for sampling equipment are assumed to be incurred during site characterization studies. The monthly rental cost for an activated carbon unit is estimated to be $750 per unit. This analysis assumes that two activated carbon units will be used per year for a total annual cost of about $18,000.

This cost estimate assumes that the system requires injection of about three, 55-gallon drums of HCl per month and three, 55-gallon drums of biocide per month. Given the costs of a 55-gallon drum of HCl of

$400 and a 55-gallon drum of biocide of $500, annual acid and biocide solution costs are estimated to be $14,400 and $18,000, respectively.

Total consumables and supplies costs are estimated to be $50,400 annually.

4.2.7 Utilities Costs

The major utility demand for this project was electricity, primarily to run the blower and associated control systems. Assuming a blower with a 10 horsepower (HP) rating and electricity costs of $0.09 per kilowatt-hour (kWh), the annual utility cost associated with the blower would be $5,585 (10 HP x 0.7457 kW/HP x 22.8 hours per day x 365 days per year x $0.09/kWh). This analysis assumes that the treatment system would operate 22.8 hours per day or 95 percent of the time. Assuming that other energy usage, such as lights and air conditioning, account for an equal amount, the total annual utility usage was estimated to be about $11,200 annually.

Electrical costs can vary by as much as 50 percent, depending on geographical location and local utility rates. This analysis assumes that no alternative sources of electrical power, such as a diesel-powered generator, would be used as backup.

4.2.8 Effluent Treatment and Disposal Costs

Other than the offgas, no other effluent or wastes are generated by the operation of the NoVOCs™ system. This analysis assumes that the activated carbon units will be replaced every 3 months. The actual frequency of replacement will be primarily dependent on contaminant concentration and air flow rate. Based on vendor quotes, the costs for reactivating carbon is estimated to be about $1,000 for each unit. This cost includes transportation, reactivation, and a change-out unit. Total annual replacement costs are therefore estimated to be $8,000.

During the SITE demonstration at NAS North Island, Site 9, the NoVOCs™ system offgas was treated using the Thermatrix Flameless Oxidation System. The Thermatrix system was selected by the Navy because it can destroy organic compounds with a removal efficiency of 99.99 percent, and on-site treatment of contaminants is the treatment method preferred by the local community. Based on cost information provided by SWDIV, the total cost of the Thermatrix system during the NoVOCs™ demonstration was about $989,000. This cost includes system acquisition, installation, operation, maintenance, monitoring, and source testing. A detailed breakdown of these costs is provided in Table 18. The Thermatrix system costs are provided for information purposes only. The cost analysis assumes that a more common offgas treatment method, activated carbon, is used to treat the NoVOCs™ offgas.

4.2.9 Residuals and Waste Shipping and Handling Costs

No residuals or wastes are generated from the operation of the NoVOCs™ system. Drill cuttings, however, would be generated during installation and removal of the system well, and purge water would be generated from periodic sampling activities. Disposal of wastes generated during removal of the system well are addressed in Section 4.2.12, Demobilization Costs. Disposal of drilling wastes (cuttings) from installation activities are assumed to occur in the first year after installation. This cost estimate assumes that the cuttings are not characteristically hazardous but that the cuttings are disposed of at a licensed hazardous waste disposal facility. The cost for disposal of the cuttings is estimated to be $10,000 and includes transportation, treatment, and disposal as a bulk solid in a landfill.

For the purge water, this analysis assumes that the contaminant concentration would be below RCRA regulatory levels that require storage and treatment as a hazardous waste. Purge water would be collected in 55-gallon carbon-steel drums and disposed of at an off-site industrial wastewater treatment and disposal facility. This analysis assumes that about 150 gallons of purge water would be generated during each quarterly sampling event. This analysis further assumes that a licensed waste hauler would transfer the wastes from the drums into a tanker truck and that the purge water would be transported about 100 miles to the nearest industrial wastewater treatment facility. Transportation costs (including pumping and labor costs) are estimated to be $700 per trip, and disposal costs are estimated to be $0.25 per gallon. Purge water disposal costs are therefore estimated at about $3,000.

Total annual residuals and waste shipping costs in the first year of operation are estimated to be $13,000. Total annual costs for the subsequent years are estimated to be $3,000. The high residuals and waste shipping costs during the first year are associated the disposal of soil cutting.

TABLE 18

COSTS ASSOCIATED WITH THE THERMATRIX SYSTEM
NoVOCs™ SITE Demonstration
Site 9, NAS North Island, California

Cost Categories	Costs in 1999 Dollars
Project Management	$106,000
Engineering	$87,000
Plan Preparation	$33,000
System Manufacturing	$300,000
Site Installation	$97,000
Sampling and Analysis	$98,000
Operation	$113,000
Travel	$14,000
Source Testing	$141,000
Total	**$989,000**

4.2.10 Analytical Services Costs

Analytical costs include laboratory analyses, data reduction and tabulation, QA/QC, and reporting. This analysis assumes that the following samples would be collected and analyzed for VOCs using EPA-approved methods: a total of 50 groundwater and air samples collected during system startup and shakedown, untreated and treated groundwater and air samples collected from the NoVOCs™ well once per month, and groundwater samples collected from each of the eight surrounding monitoring wells quarterly. In addition, QA/QC samples consisting of a trip blank, a field and equipment blank, a field duplicate, and MS/MSD samples will be collected during each quarterly sampling event. Assuming an analytical cost of $150 per sample, startup and shakedown analytical costs would be $7,500 (50 samples x $150 per sample). Monthly analytical costs would be $600 (2 groundwater and 2 air samples x $150 per sample) or about $7,200 annually. Quarterly laboratory analytical costs would be $2,400 ([8 groundwater and 2 air samples + 6 QA/QC samples] x $150 per sample) or about $9,600 annually. Data reduction, tabulation, data validation, and reporting is estimated to cost about $1,000 per quarter or

$4,000 per year. Total annual analytical services costs are therefore estimated to be about $28,300 in the first year and $20,800 per year thereafter.

4.2.11 Maintenance and Modification Costs

This cost analysis does not include labor, materials, and equipment costs associated with major maintenance requirements or modifications to the system. Annual maintenance requirements are assumed to consist of the removal of the internal well components for cleaning, inspection, and replacement, if necessary. Annual maintenance costs are estimated to be $10,000. Costs for routine maintenance and repairs are included in the labor costs presented in Section 4.2.5, Labor Costs.

4.2.12 Demobilization Costs

Site demobilization includes shutdown, disassembly, well plugging and abandonment, and transportation and disposal of equipment to a licensed hazardous waste disposal facility. Well plugging and abandonment procedures consist of overdrilling the well and pressure grouting the boring to the ground surface. Demobilization would occur at the end of the groundwater remediation project and is estimated to take about 5 days to complete. This analysis assumes that the NoVOCs™ technology would have no salvage value at the end of the project. The majority of the demobilization costs apply to waste disposal, which is estimated to be about $10,000. This estimate assumes that the waste is not characterized as hazardous. The wastes requiring disposal include the casing and filter pack from overdrilling, the NoVOCs™ system itself, and ancillary piping and equipment associated with the carbon adsorption units. The total volume of waste is assumed to be 30 cubic yards. The cost for waste disposal includes transportation and labor. Labor costs associated with all activities other than well plugging and abandonment during demobilization would include two technicians working 5 8-hour days and are estimated to be about $4,000 (80 hours x $50 per hour); labor costs associated well plugging and abandonment are accounted for in the waste disposal cost. Total demobilization costs are therefore estimated to be about $14,000.

4.3 COST SUMMARY

This section summarizes the estimated costs in 1999 dollars for using the NoVOCs™ system under the conditions described in the previous sections. Table 17 presents a breakdown of costs for the 12 categories previously identified. The table presents fixed costs and annual variable costs and compares the costs for groundwater treatment projects with durations of 1, 3, 5, and 10 years. The cost of treatment per unit volume of water was not calculated because of the number of assumptions required to make such a calculation, including shape and size of the NoVOCs™ circulation cell, amount of water recirculated by the system, contaminant type and concentration, type of offgas treatment system used, and treatment goals. These factors are site-specific. Therefore, treatment costs per unit volume of water will vary greatly from project to project. The cost estimate for each category and total costs were rounded to two significant numbers. One-time capital costs for a single treatment unit were estimated to be $190,000; annual operation and maintenance costs were estimated to be $160,000 for the first year and $150,000 per year thereafter. Based on these estimates, the total cost for operating a single NoVOCs™ system was calculated to be $350,000 for 1 year, $670,000 for 3 years, $1,000,000 for 5 years, and $2,000,000 for 10 years. These costs include a 4 percent annual inflation rate. Costs for implementing a NoVOCs™ system at another site may vary substantially from this estimate for the SITE demonstration.

5.0 CONCLUSIONS

This section presents the conclusions of the SITE evaluation of the NoVOCs™ technology at NAS North Island, Site 9. The NoVOCs™ system did not function without operational difficulties in the highly saline aquifer containing groundwater with TDS ranging from 18,000 to 41,000 mg/L, which represents an extreme geochemical environment. Conclusions are presented for operation and maintenance of the NoVOCs™ system and for each demonstration objective.

Operation and Maintenance. Operation and maintenance of the NoVOCs™ system was conducted primarily by Bechtel with assistance from MACTEC. The NoVOCs™ system was designed to operate continuously, 24 hours a day, 7 days a week. However, during the demonstration, the system experienced significant operational difficulties and was limited to four main operating periods: System Startup and Shakedown (February 26 through March 26, 1998), Early System Operation (April 20 through June 19, 1998), Reconfiguration Operation (September 24 through October 30, 1998), and Final Configuration Operation (December 4, 1998 through January 4, 1999).

Beginning in early May 1998, the NoVOCs™ system began experiencing operating problems associated with high water levels in the NoVOCs™ well and lower-than-designed pumping rates. Initially, it was thought that the flow sensor was not accurately measuring the pumping rate. However, as system operation progressed, the continued low pumping rate and increased frequency of the high water level in the NoVOCs™ well suggested that a more significant problem was occurring. By June 1998, the pumping rate had been reduced from the design rate of 25 gpm to about 5 gpm. Based on discussions between the Navy and the technology vendor, the system was shut down on June 19, 1998, to evaluate the cause of the poor performance. Suspected causes for the poor performance included (1) biofouling or scaling of the screen intervals and formation near the NoVOCs™ well, (2) possible differences in hydraulic characteristic between the upper and lower portions of the aquifer, and (3) design problems with the NoVOCs™ well, in particular, the length of the recharge screen.

To evaluate the recharge capacity of the NoVOCs™ system and provide information on the hydraulic characteristics of the aquifer in the vicinity of the NoVOCs™ system, a down-well video tape survey and a series of aquifer hydraulic tests were conducted. Based on the aquifer testing, it was concluded that the NoVOCs™ well should be able to sustain the design pumping rate of 25 gpm. However, during the video tape survey, fouling of the NoVOCs™ well screens by iron precipitation and microbiological growth was observed, which appeared to have impaired the performance of the NoVOCs™ system by obstructing the well screen and filter pack. Attempts to control fouling by addition of a commercial surfactant product and a commercial biocide were unsuccessful, and the failure to control the fouling eventually caused the termination of the demonstration in January 1999.

Based on the results of the SITE demonstration at NAS North Island and other recirculating well evaluations, well fouling is a recognized problem that requires an appropriate design as well as operation and maintenance activities for successful management. In-well stripping systems and recirculating wells, such as the NoVOCs™ system, are subject to fouling from a variety of common causes. The three most common causes of fouling are (1) accumulation of silt in the well structure, (2) biofouling by colonizing microorganisms, and (3) formation of chemical precipitates and insoluble mineral species. These issues can sometimes be controlled through appropriate design and construction of filter pack and well screens, groundwater pH control to manage formation of chemical precipitates and insoluble mineral species, and injection of a suitable biocide to prevent biofouling. However, any design that does not provide geochemical controls based on site-specific hydrogeologic and geochemical conditions is likely to experience significant operation and maintenance problems due to fouling.

Demonstration Objectives. The conclusions relative to each primary and secondary evaluation objective are summarized below:

Primary Objectives:

P1 Evaluate the removal efficiency of the NoVOCs™ well system for VOCs in groundwater.

Comparison of VOC results for groundwater samples taken adjacent to the influent and effluent of the NoVOCs™ system indicated that 1,1-DCE, cis-1,2-DCE, and TCE concentrations were reduced by greater than 98, 95, and 93 percent, respectively, in all the events, except the first sampling event, which was conducted during system shakedown activities. Excluding the first sampling event, the mean concentrations of 1,1-DCE, cis-1,2-DCE, and TCE in the water discharged from the NoVOCs™ system were about 27, 1,400, and 32 micrograms per liter (Fg/L), respectively. The 95 percent upper confidence limits of the means for 1,1-DCE, cis-1,2-DCE, and TCE in the treated groundwater were calculated to be about 37, 1,760, and 46 Fg/L, respectively. The maximum contaminant levels (MCL) for these compounds in groundwater are 6 Fg/L for 1,1-DCE, 6 Fg/L for cis-1,2-DCE, and 5 Fg/L for TCE. MACTEC claims that the NoVOCs™ system can reduce effluent VOC concentrations to below MCLs if the contaminant source has been removed. Since dense nonaqueous-phase liquids may be present in the aquifer at the site and may act as a continuing source of groundwater contamination, MACTEC did not make any claims for reduction of VOC concentrations in groundwater at Site 9.

P2 Determine the radial extent of the NoVOCs™ treatment cell.

Because of the sporadic operation of the NoVOCs™ system, a direct evaluation of the radial extent of the NoVOCs™ treatment cell was not conducted. In lieu of direct evaluation method, aquifer hydraulic tests conducted to assess the hydrogeologic characteristics of the site were used to indirectly evaluate the potential radial extent of the NoVOCs™ treatment cell. Although the aquifer pump tests cannot be directly applied to evaluate the radial extent of the NoVOCs™ treatment cell or even that groundwater recirculation was established, the test data does provide information on the radius of influence of the well under pumping (2-dimensional) and dipole (3-dimensional) flow conditions. The resulting changes in pressure head provide an indication of the potential for flow in the surrounding aquifer and are used to provide an estimate of the radial extent of influence created by the NoVOCs™ well. However, the pressure head changes do not accurately represent flow patterns or contaminant transport. Consequently no firm conclusions can be drawn about the radial extent of the NoVOCs™ treatment cell.

During the constant discharge rate (discharge = 20 gpm) pumping test, measurable drawdowns were observed at about 100 feet from the NoVOCs™ well in all directions and different depths. This information indicates that the radius of influence by extraction, specifically at 20 gpm, could be as large as 100 feet. The dipole flow test data shows that measurable pressure responses occur at crossgradient locations 30 feet from the NoVOCs™ well and may be observed at farther distances. However, no drawdowns or water level rises could be positively measured in monitoring wells beyond the 30-foot distance.

P3 Quantify the average monthly total VOC mass removed from groundwater treated by the system for 6 months.

Because of operational problems with the NoVOCs™ system, the mass of VOCs removed by the NoVOCs™ system was evaluated during a limited period of operation from April 28 to June 8, 1998. During this period, the average total VOC mass removed by the NoVOCs™ system ranged from 0.01 to 0.14 pounds per hour (lb/hr) and averaged 0.10 lb/hr during the five sampling events. Accounting for the sporadic operation of the NoVOCs™ system, the mass of total VOCs removed during the entire operation period from April 20 through June 19, 1998, was estimated to be about 90 pounds.

<u>Secondary Objectives:</u>

S1 Quantify the changes in VOC concentrations in the groundwater within the NoVOCs™ treatment cell.

VOC concentrations appear to be stratified in the aquifer. In general, the highest concentrations of the three primary VOCs, 1,1-DCE, cis-1,2-DCE, and TCE, were detected in the deep monitoring wells. This trend was especially pronounced for cis-1,2-DCE, which was detected at concentrations between 440 and 96,000 Fg/L in the deep wells, but only between 120 and 1,200 Fg/L in the shallow wells. The intermediate wells generally had the lowest concentration of all three primary VOCs. Because of the limited amount of data collected and operational problems with the NoVOCs™ system throughout the demonstration, trends in the VOC concentration data associated with operation of the NoVOCs™ system were not apparent.

S2 Document changes in selected geochemical parameters that may be affected by the NoVOCs™ system.

Groundwater samples were collected and analyzed for dissolved metals, alkalinity, total organic carbon, and dissolved organic carbon to evaluate changes in the selected geochemical parameters caused by the NoVOCs™ system. Despite the possible iron fouling problems experienced in the NoVOCs™ well, the groundwater analytical results for dissolved metals exhibited no clear trends in the data that would suggest that precipitation of dissolved metals was occurring in the aquifer. Based on a review of the data, alkalinity, total organic carbon, and dissolved organic carbon results remained relatively unchanged during the demonstration. Total dissolved solid concentrations showed an increasing trend with depth;

however, concentrations did not appear to be affected by operation of the NoVOCs™ system. Conductivity and salinity values measured in the field also increased with depth and appeared to correlate with the analytical results for total dissolved solids. No clear trends were apparent from the field measurements of temperature, pH, and dissolved oxygen, and insufficient data were collected to adequately evaluate trends associated with oxidation/reduction potential.

S3 Document NoVOCs™ system operating parameters.

During the four operational periods, Bechtel measured the NoVOCs™ system operating parameters, including air temperature, pressure, flow rate, water pumping rate, and pH in the groundwater effluent. The average air temperature at the well intake during the four operational periods ranged from 132 to 152 ^{o}F; the pressure ranged from 2.2 to 3.3 pounds per square inch; and air flow ranged from 52.4 to 69.0 standard cubic feet per minute. The water pumping rate within the NoVOCs™ well varied throughout the demonstration; however, based on data provided by SWDIV, the pumping rate ranged from 8 to 34 gpm. Additionally, the average pH in the groundwater effluent during the four operational periods ranged from 3.60 to 7.28.

S4 Document pre- and post-treatment VOC concentrations and system operating parameters in the Thermatrix flameless oxidation offgas treatment system.

Based on a comparison of influent and effluent air samples collected from the Thermatrix system, total VOC concentrations in the 1-hour composite samples collected from the influent ranged from 22,120 to 59,200 parts per billion (ppb) on a volume per volume (v/v) basis and averaged 45,200 ppb v/v during the five sampling events. Total VOC concentrations in the 1-hour composite samples collected from the effluent air sample port ranged from 2.8 to 7.2 ppb v/v and averaged 4.8 ppb v/v during the five sampling events. Total VOC concentrations measured in the Thermatrix influent air sample port were reduced by greater than 99.9 percent in all five sampling events.

S5 Document the hydrogeologic characteristics at the treatment site.

Based on the results of the hydrogeologic investigation conducted at the treatment site, the following hydrogeologic characteristics were determined:

- Groundwater generally flows to the west or northwest in both of the upper and lower aquifer zones. The horizontal hydraulic gradient in both aquifer zones is relatively flat, ranging from 0.005 to 0.01. Groundwater direction and velocity measurements collected from monitoring well near the shoreline of the San Diego Bay using the Colloidal Borescope indicate that groundwater flows in a west-southwest direction at an average of velocity of 5 ft/day.

- The average hydraulic conductivity was estimated as 29 ft/day or 0.01 cm/sec. The average aquifer storativity and specific yield are 0.004 and 0.07, respectively. The average ratio of horizontal to vertical hydraulic conductivity is estimated at 5.7.

- The calculated average specific capacities are 1.48 gpm/ft for the upper screened interval during pumping, 1.50 gpm/ft for the upper screened interval during injection, and 3.22 gpm/ft for the lower screened interval during pumping. The calculated average well efficiencies are 82 percent for the upper screened interval during pumping, 97 percent for the upper screened interval during injection, and 91 percent for the lower screened interval during pumping.

- The radius of influence during the constant discharge pumping test (20 gpm) was at least 100 feet based on drawdown measured at the observation wells.

- The maximum flow of clean tap water that can be injected through the upper screen of the NoVOCs™ well is 25 gpm.

- The aquifer hydraulic conditions are suitable for application of the NoVOCs™ technology. The NoVOCs™ well as designed should be able to extract and inject a flow rate of 20 gpm based on the aquifer hydraulic characteristics.

S6 Document the changes in pressure head in the aquifer caused by the NoVOCs™ system.

Pressure head changes in the aquifer caused by the NoVOCs™ system were measured in the groundwater monitoring wells in the vicinity of the NoVOCs™ system during a tidal study conducted at the treatment site before and during operation of the NoVOCs™ system. Groundwater level changes caused by startup and shutdown of the NoVOCs™ system were evident in the water level data for well cluster MW-45, MW-46, and MW-47, located about 30 feet from the NoVOCs™ well. The water level data for observation wells MW-45 (the upper screened well in this cluster) and MW-46 (intermediate screened well) showed water level increases after system startup. The groundwater elevation increase in well MW-45 was approximately 0.15 feet. Observation well MW-46, the intermediate depth well, showed a water level increase of approximately 0.05 feet. Observation well MW-47, the deep screened well, showed a water level decrease of approximately 0.025 feet. This pattern of water level increases and decreases associated with the operation of the NoVOCs™ system was expected based on the monitoring well screen locations relative to the NoVOCs™ well screen locations. The deep screened well experienced a drop in water level as water was drawn toward the NoVOCs™ well intake, and the upper screened wells experienced increases in water level as water was lifted inside of the NoVOCs™ well and discharged into the upper aquifer zone. In well pair MW-48 and MW-49 (located about 62 feet from the NoVOCs™ well) and in wells MW-50 and MW-51 (located about 91 and 105 feet, respectively, from the NoVOCs™ well), water level changes associated with NoVOCs™ system operation were not apparent.

S7 Estimate the capital and operating costs of constructing the NoVOCs™ system and Thermatrix flameless oxidation process and maintaining them for 6 months.

An economic analysis of using the NoVOCs™ and Thermatrix technologies to treat VOC-contaminated groundwater and offgas was conducted. Based on the SITE evaluation and cost information provided by the Navy and MACTEC, one-time capital costs for a NoVOCs™ system were estimated to be $190,000; annual operation and maintenance costs were estimated to be $160,000 per year for the first year and $150,000 per year thereafter. Because of the time required to remediate an aquifer is site-specific, costs have been estimated for operation of a NoVOCs™ system over a range of time for comparison purposes. Based on these estimates, the total cost for operating a single NoVOCs™ system was calculated to be $350,000 for 1 year; $670,000 for 3 years; $1,000,000 for 5 years; and $2,000,000 for 10 years. These estimates include an annual inflation rate of 4 percent.

Costs for implementing a NoVOCs™ system at another site may vary substantially from this estimate for the SITE evaluation. A number of factors affect the cost of treatment using the NoVOCs™ system, including soil type, contaminant type and concentration, depth to groundwater, site geology and hydrogeology, groundwater geochemistry, site size and accessibility, required support facilities and available utilities, type of offgas treatment unit used, and treatment goals. It is important to (1) characterize the site thoroughly before implementing this technology to ensure that treatment is focused on contaminated areas and (2) determine the circulation cell radius for the well and the resulting number of wells needed to remediate a particular site.

The cost of treatment per unit volume of water was not calculated because of the number of assumptions required to make such a calculation and the limited duration of system operation. Because of the site-specific nature of treatment costs, costs per unit volume of water will vary greatly from project to project.

Based on cost information provided by SWDIV, the total cost of the Thermatrix system during the NoVOCs™ demonstration was about $989,000. This cost includes system acquisition, installation, operation, maintenance, monitoring, and source testing.

6.0 TECHNOLOGY STATUS

This section presents the NoVOCs™ technology status and was written solely by MACTEC. The statements presented in this section represent the vendor's point of view and summarize the claims made by the vendor regarding the NoVOCs™ system. Publication of this material does not represent the EPA's approval or endorsement of the statements made in this section; results of the performance evaluation of the NoVOCs™ at NAS North Island are discussed in the previous sections of this report. In addition, case studies provided by the vendor that document the performance of the NoVOCs™ technology at other sites is presented in Volume I, Appendix B.

MACTEC Environmental Technologies Company (MACTEC) acquired an exclusive license to the NoVOCs in-well volatile organic compound (VOC) stripping system from EG&G Environmental during December of 1997. Along with the license, MACTEC also continued on-going support of the NoVOCs demonstration at Installation Restoration Site No. 9 at the Naval Air Station (NAS) North Island in San Diego, California. To complete the demonstration project and maintain continuity of the project team working on the project, MACTEC subcontracted much of the design and implementation to a number of individuals recommended by the Navy who were working on the project prior to MACTEC's involvement.

In June of 1999, MACTEC acquired 26 patents covering the equipment, use, and application of groundwater recirculating well technology (RWT). These patents were purchased from the inventors of the technology, IEGmbH (IEG) and included the well known UVB process as well as other RWT arrangements. MACTEC acquired the NoVOCs and IEG technologies for several fundamental reasons:

- Proven Success in Field Applications. These technologies have been applied at a variety of test sites as well as on site remediation projects since early 1990s. At the time of MACTEC'S acquisition there were over 30 successful applications of the NoVOCs type systems and well over 300 IEG type RWT wells worldwide. In fact there are documented site closures for a number of these wells. The technologies have been installed in various geological formations (including fractured bedrock), been applied to VOCs as well as non-volatile compounds, and have been used for enhanced free product recovery, enhanced mass removal from soil and groundwater, bioremediation, treatment of VOCs, and other applications. (A partial listing of NoVOCs and IEG type systems is provided in Section 6.2).

- Superior Field Performance. MACTEC's research prior to acquisition of the technologies indicated that many RWT systems were selected at sites where pump and treat type systems had or would fail to remove significant contaminant mass. The NoVOCs's and IEG type RWT systems are proven to remove mass at higher rates than pump and treat systems mainly due to the dynamics of the groundwater recirculation zone. At one recent application, the mass of VOCs removed was nearly an order of magnitude larger than what was anticipated based on nearby pump and treat type systems. Field experience has also shown that the stripping efficiency of the NoVOCs and IEG type RWT systems can be tailored to the site needs and can be designed to be competitive with any system on the market.

- Increasing Acceptance as a Viable Alternative. MACTEC's research indicated a preference among many owners of sites requiring remediation and state regulators toward the RWT approach due to its targeted mass removal. The combination of RWT, for source removal, with intrinsic remediation is also becoming widely considered as a preferred approach.

- Life Cycle Remedial Cost. From the limited data available on completed life cycles for RWT, pump and treat, and other remedial solutions, RWT scores very well, coming in at one-half to one-fifth the overall cost. (e.g., Quinton, G.E., et. Al., 1997, "A Method to Compare Groundwater Cleanup Technologies". Remediation (Autumn) 7 - 16).

The above information is not provided to suggest that the NoVOCs systems and RWT systems can be applied without proper geologic and design considerations. Like other technologies, NoVOCs and RWT systems have limitations to their application and are not applicable to all types of contaminants in all geologies. In fact, the results of the NAS North Island demonstration emphasize this fact since the geology and groundwater conditions resulted in fouling of the well and certainly would have also led to the fouling of a pump and treat system had it been applied in the same conditions.

The technologies do have broad use in the remediation market place and design considerations can be put in place to overcome field constraints. For example, where iron fouling of RWT is likely, closed loop systems have proven to minimize fouling. A closed loop NoVOCs system operating at a landfill in Washington State has had minimal problems operating in a high iron environment since there is very little oxygen in the gas being circulated in the closed loop system. Likewise, several IEG type RWT systems operating in the closed loop mode have confirmed that removing the oxygen from the system minimizes the fouling potential.

MACTEC's key components for a good design of a NoVOCs or RWT system are as follows:

- Understanding of the hydrogeology. For RWT systems this is typically collected in a dual screen pump test that yields a vertical hydraulic conductivity. This pump test data can be used in MACTEC's models to predict the zone of influence and performance of the RWT system.

- Understanding the geochemistry. Typically collected with groundwater analytical data, the interaction of an process with the groundwater and soil environment needs to be assessed to select pre- or post-treatments that will avoid fouling and to design a system that will function properly.

- Understanding the contaminant distribution. Targeted use of the RWT systems can be achieved through proper site investigation.

- Flexibility in technology selection. MACTEC provides a suite of technologies from very simple air lift systems to highly engineered RWT systems. Selecting the correct components to match the site conditions is critical to success.

- Understanding of the remedial decision making process. There are points in site remediation projects where goals can change based on changed conditions. Flexibility in understanding this aspect of remedial projects can lead to cost-effective decisions.

- Employing the proper project team. MACTEC has found that, whether considering the managers, designers, or field implementation team, the quality of people involved with the project can make or break a RWT system.

Further information on case histories of NoVOCs and IEG type RWT projects, economic analysis of RWT systems compared to other technologies, and the suite of technologies that can be applied to recirculation well remedial systems are available from, and are being expanded on by MACTEC. If you have questions or comments contact Joe Aiken at MACTEC, Inc., 1819 Denver West Drive, Suite 400, Golden, Colorado 80401, (303) 273-5082.

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